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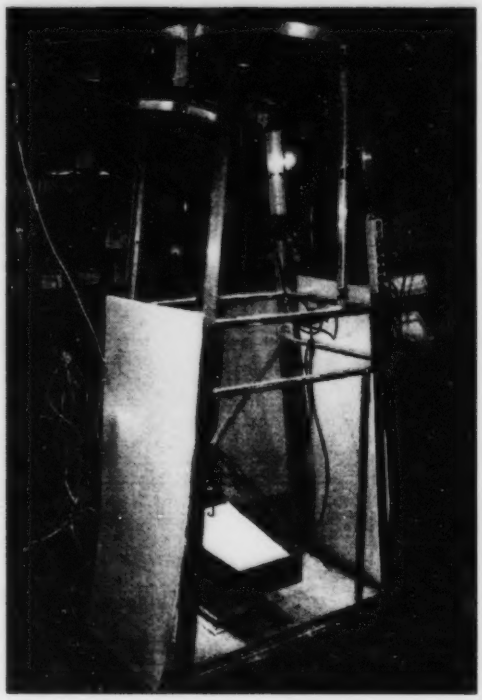
TP 13488E

A Snow Generation System – Prototype Testing



by

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APS AVIATION INC.

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Un sommaire français se trouve avant la table des matières.

PREFACE

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to advance aircraft ground deicing/anti-icing technology. The specific objectives of the APS test program are the following:

- To develop holdover time tables for new anti-icing fluids, and to validate fluid-specific and SAE holdover time tables;
- To gather enough supplemental experimental data to support the development of a deicing-only table as an industry guideline;
- To examine conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft when subjected to speeds up to and including rotation;
- To measure the jet-blast wind speeds developed by commercial airliners in order to generate air-velocity distribution profiles (to predict the forces that could be experienced by deicing vehicles), and to develop a method of evaluating the stability of deicing vehicles during live deicing operations;
- To determine the feasibility of examining the surface conditions on wings before takeoff through the use of ice-contamination sensor systems, and to evaluate the sensitivity of one ice-detection sensor system;
- To evaluate the use of warm fuel as an alternative approach to ground deicing of aircraft;
- To evaluate hot water deicing to determine safe and practicable limits for wind and outside ambient temperature;
- To document the appearance of fluid failure, to measure its characteristics at the point of failure, and to compare the failures of various fluids in freezing precipitation;
- To determine the influence of fluid type, precipitation (type and rate), and wind (speed and relative direction) on both the locations and times to fluid failure initiation, with special attention to failure progression on the Bombardier Canadair Regional Jet and on high-wing turboprop commuter aircraft;
- To evaluate snow weather data from previous winters to identify a range of snow-precipitation suitable for the evaluation of holdover time limits;
- To compare the holdover times from natural and artificial snow trials and to evaluate the functionality of NCAR's prototype simulated snowmaking system; and
- To develop a plan for implementing a full-scale wing test facility that would enable the current testing of deicing and anti-icing fluids in natural and artificial freezing precipitation on a real aircraft wing.

The research activities of the program conducted on behalf of Transport Canada during the 1998-99 winter season are documented in twelve reports. The titles of these reports are as follows:

- TP 13477E Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1998-99 Winter;
- TP 13478E Aircraft Deicing Fluid Freeze Point Buffer Requirements for Deicing Only Conditions;
- TP 13479E Contaminated Aircraft Takeoff Test for the 1998-99 Winter;
- TP 13480E Air Velocity Distribution Behind Wing-Mounted Aircraft Engines;
- TP 13481E Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks;
- TP 13482E Evaluation of Warm Fuel as an Alternative Approach to Deicing;
- TP 13483E Hot Water Deicing of Aircraft;
- TP 13484E Characteristics of Failure of Aircraft Anti-Icing Fluids Subjected to Precipitation;
- TP 13485E Aircraft Full-Scale Test Program for the 1998-99 Winter;
- TP 13486E Evaluation of Snow Weather Data for Aircraft Anti-Icing Holdover Times;
- TP 13487E Development of a Plan to Implement a Full-Scale Test Site; and
- TP 13488E A Snow Generation System – Prototype Testing.

This report, TP 13488E has the following objective:

- To compare the holdover times from natural and artificial snow trials and to evaluate the functionality of NCAR's prototype simulated snowmaking system.

This objective was met by conducting a series of artificial snow trials in a cold-chamber laboratory. Test parameters included ambient temperature, precipitation rate, and test fluid. The following trial results were recorded: fluid failure times, snow appearance, and snowmaking-system functionality.

ACKNOWLEDGEMENTS

This research has been funded by the Civil Aviation Group, Transport Canada, and with support from the Federal Aviation Administration. This program could not have been accomplished without the participation of many organizations. APS would like to thank, therefore, the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, the National Research Council Canada, Atmospheric Environment Services Canada, Transport Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Delta Air Lines, Royal Airlines, Air Canada, the National Research Council Canada, Canadian Airlines International, AéroMag 2000, Aéroport de Montreal, the Greater Toronto Airport Authority, Hudson General Aviation Services Inc., Union Carbide, RVSI, Cox and Company Inc., the Department of National Defence, and Shell Aviation, for provision of personnel and facilities and for their co-operation on the test program. APS would like also to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data.

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16. Abstract

At the request of Transport Canada's Transportation Development Centre and the FAA, APS Aviation Inc. undertook a research program to evaluate a prototype snow generation system being developed by the National Center for Atmospheric Research (NCAR) under contract to the FAA, and to compare the holdover times from natural and artificial snow.

A total of 24 Type IV trials and 40 Type I simulated snow trials were conducted on two occasions at the National Research Council's Climatic Engineering Facility in Ottawa. All failure calls were made according to flat plate failure call standards.

Type IV fluids were tested at neat and 75/25 concentration, and the Type I fluids were diluted with hard water to obtain fluids with a freeze point 10°C below the ambient air temperature. The NCAR snowmaking machine was operated according to the NCAR guidelines in the operators' manual supplied with the system.

The simulated snow exhibited significant differences from natural snow. The failure times observed for both Type I and Type IV fluids were much shorter than the published holdover times. Enhancements to the snowmaking machine were recommended to address problems with the system.

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Les rapports de recherche produits au nom de Transports Canada sur les essais réalisés au cours des hivers antérieurs peuvent être obtenus auprès du Centre de développement des transports (CDT). Le programme de la saison hivernale a donné lieu à douze rapports (dont celui-ci). On trouvera dans la préface l'objet de ces rapports. Le financement a été assuré en partie par la FAA.

16. Résumé

À la demande du Centre de développement des transports de Transports Canada et de la FAA, APS Aviation Inc. a entrepris un programme de recherche visant à évaluer un prototype de machine à fabriquer de la neige mis au point par le National Center for Atmospheric Research (NCAR) pour le compte de la FAA, et à comparer les durées d'efficacité des fluides antigivrage sous neige naturelle et artificielle.

Les essais, menés en deux temps, ont eu lieu à l'Installation de génie climatique du Conseil national de recherches du Canada, à Ottawa. Ils comportaient au total 24 essais de fluides de type IV et 40 essais de fluides de type I sous précipitations de neige artificielle. Les chercheurs ont appliqué les critères de perte d'efficacité sur plaques planes de la SAE pour déterminer la durée d'efficacité des fluides testés.

Les fluides de type IV ont été essayés à l'état pur et à une concentration de 75/25, tandis que les fluides de type I étaient dilués avec de l'eau dure, de façon à obtenir des fluides dont le point de congélation était de 10 degrés Celsius inférieur à la température de l'air ambiant. La machine à fabriquer de la neige du NCAR était exploitée conformément aux instructions du NCAR énoncées dans le manuel fourni avec la machine.

Des différences marquées ont été observées entre la neige artificielle et la neige naturelle. Ainsi, les durées d'efficacité des fluides de type I et de type IV étaient beaucoup plus courtes, sous neige artificielle, que celles indiquées par les tables. L'équipe de recherche a recommandé des améliorations à la machine à fabriquer de la neige.

17. Mots clés	18. Diffusion
Neige artificielle, machine à fabriquer de la neige, dégivrage, antigivrage	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires. Courriel : *tdccdt@tc.gc.ca*

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EXECUTIVE SUMMARY

Introduction

At the request of Transport Canada's Transportation Development Centre and the FAA, APS Aviation Inc. undertook a research program to evaluate a prototype snow generation system being developed by the National Center for Atmospheric Research (NCAR) under contract to the FAA, and to compare holdover times from natural and artificial snow.

Procedures and Data Processing

A total of 24 Type IV trials and 40 Type I indoor snow trials were conducted on two occasions at the National Research Council's Climatic Engineering Facility in Ottawa. All failure calls were made according to flat plate failure call standards.

Type IV fluids were tested at neat and 75/25 concentration, and the Type I fluids were diluted with hard water to obtain fluids with a freeze point 10°C below the ambient air temperature. Type IV fluids include an ethylene glycol-based fluid, a propylene glycol-based fluid, and the reference fluid (Fluid X); eight Type I fluids were tested. The NCAR snowmaking machine was operated according to the NCAR guidelines in the operators' manual supplied with the system.

Conclusions

The artificial snow exhibited significant differences from natural snow. Failure times observed for both Type I and Type IV fluids were much shorter than the published holdover times. Type IV fluid holdover times were up to 68 percent shorter and Type I fluid times were up to 73 percent shorter. The failure patterns observed in artificial snow were noticeably different from those seen in natural snow. Snow bridging was detected earlier in the failure progressions during artificial snow conditions.

The snowmaking system was evaluated during the trials. Difficulties with the rate logging capability and other systems resulted in a list of recommended modifications to be included in the final delivery model.

The differences between natural and artificial snow should be further evaluated and the modified snowmaking systems will require more testing.

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SOMMAIRE

Introduction

À la demande du Centre de développement des transports de Transports Canada et de la FAA, APS Aviation Inc. a entrepris un programme de recherche visant à évaluer un prototype de machine à fabriquer de la neige mis au point par le National Center for Atmospheric Research (NCAR) pour le compte de la FAA, et à comparer les durées d'efficacité des fluides antigivrage sous neige naturelle et artificielle.

Description des essais et traitement des données

Les essais, menés en deux temps, ont eu lieu à l'intérieur de l'Installation de génie climatique du Conseil national de recherches du Canada, à Ottawa. Ils comportaient au total 24 essais de fluides de type IV et 40 essais de fluides de type I sous précipitations de neige artificielle. Les chercheurs ont appliqué les critères de perte d'efficacité sur plaques planes de la SAE pour déterminer la durée d'efficacité des fluides testés.

Les fluides de type IV ont été essayés à l'état pur et à une concentration de 75/25, tandis que les fluides de type I étaient dilués avec de l'eau dure, de façon à obtenir des fluides dont le point de congélation était de 10 degrés Celsius inférieur à la température de l'air ambiant. Les fluides de type IV comprenaient un fluide à base d'éthylèneglycol, un fluide à base de propylèneglycol et le fluide de référence (fluide X); huit fluides de type I ont été testés. La machine à fabriquer de la neige du NCAR était exploitée conformément aux instructions du NCAR énoncées dans le manuel fourni avec la machine.

Conclusions

Des différences marquées ont été observées entre la neige artificielle et la neige naturelle. Les durées d'efficacité des fluides de type I et de type IV étaient beaucoup plus courtes, sous neige artificielle, que celles indiquées par les tables. Ainsi, les durées d'efficacité respectives des fluides de type IV et des fluides de type I étaient jusqu'à 68 p. cent et 73 p. cent plus courtes sous neige artificielle que sous neige naturelle. Le comportement des liquides jusqu'à la perte d'efficacité était passablement différent selon qu'ils étaient sous neige naturelle ou artificielle : le pontage de neige se produisait plus tôt dans le deuxième cas.

Les essais furent également l'occasion d'évaluer le fonctionnement de la machine à fabriquer de la neige. Certaines difficultés touchant entre autres le

logiciel d'enregistrement des taux de précipitations ont amené les chercheurs à recommander une liste de modifications à apporter à la version définitive de la machine.

Il y a lieu d'approfondir les différences entre la neige naturelle et la neige artificielle et de soumettre à d'autres essais la nouvelle version de la machine à fabriquer de la neige.

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GLOSSARY

APS	APS Aviation Inc.
FAA	Federal Aviation Administration
NCAR	National Center for Atmospheric Research
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre
UCAR	Union Carbide

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1. INTRODUCTION

At the request of the Transportation Development Centre of Transport Canada and the FAA, APS Aviation Inc. undertook a research program to evaluate a prototype snow generation system being developed by the National Center for Atmospheric Research (NCAR) under contract to the FAA and to compare holdover times from natural and artificial snow. This study was part of the winter 1998-99 research program on deicing, as described in the detailed work statement shown in Appendix A.

Trials were conducted at the National Research Council Climatic Engineering Facility in Ottawa. Types I and IV fluids were tested in artificial snow conditions at various ambient air temperatures and precipitation rates to obtain fluid failure times for the artificial snow conditions created by the NCAR snowmaking machine.

This body of tests was designed to investigate snowmaker functionality as well as fluid failure times and failure progressions resulting from artificial snow precipitation. Failure times and mechanisms were compared with holdover time tables generated from natural precipitation tests.

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2. METHODOLOGY

This section describes the methods used to perform the indoor snow trials.

2.1 Test Site

The indoor snow trials were conducted on two occasions at the National Research Council Climatic Engineering Facility in Ottawa (see Photos 2.1 and 2.2). The trials with Type IV fluids were performed in April 1999 and the trials with Type I fluids in July 1999.

2.2 Description of Test Procedures

The test procedure established by APS for the snowmaker trials is included in Appendix B.

All trials, including Type I and Type IV trials, were conducted according to the guidelines set out in the procedure described below. All failure calls were made according to flat plate failure call standards for snow precipitation. The trials were performed on a standard aluminum plate fixed to the fluid collection bucket of the snowmaker assembly. The plate and collection bucket assembly were levelled to maintain the test surface at a 10° incline.

The procedure for artificial snow trials was similar to the standard holdover time procedure used by APS in natural snow.

The major steps in the artificial snow flat plate test procedure were:

1. Empty fluid collection bucket;
2. Prepare and secure ice core;
3. Begin precipitation and data logging;
4. Clean panels and start;
5. Apply (pour) fluids to test panels. Type I fluids are at room temperature. Type II and Type IV fluids are at the test air temperature. Fluids are poured using a single-step fluid application;
6. Record the start of the holdover time after fluid is applied;
7. Record crosshair end condition times; and
8. Continue testing until at least five crosshairs or one third of the plate have failed.

The Type IV fluids were tested at neat and 75/25 concentration. The Type I fluids were diluted with hard water to obtain fluids with a freezing point

10°C below the ambient air temperature. For example, a fluid with a freeze point of -20°C was used for the trials at -10°C air temperature.

The snowmaking machine was operated according to the guidelines set forth in the NCAR operator's manual supplied with the system. This manual is included in Appendix D.

2.3 Data Forms

The data form employed during the indoor snow trial is shown in Figure 2.1. A single data form was required for each test due to the automatic rate logging capability of the system.

2.4 Equipment

The snowmaking machine is a complex assembly of components. It operates by feeding a 7 cm diameter ice core of purified-water ice into a carbide-tipped spur bit at a controlled rate. The feed rate is determined by a series of high frequency pulses generated with a notebook PC and output to a stepper motor control circuit and to the stepper motor. The ice flakes are then redistributed semi-randomly by a series of fans. They fall 3.4 m to a standard aluminum plate supported by a fluid trap. The plate and fluid trap rest on a 0.1 g resolution, 6 100 g capacity, analytical balance so that total mass and snowfall rate can be measured in real time. A high-resolution (analog devices) temperature transmitter monitors a temperature channel. The temperature sensor uses a 1.5 mm o.d., 100 ohm platinum resistance temperature detectors (RTD).

A complete list of equipment is included in the test procedure outlined in Appendix B.

2.5 Fluids

The Type I fluids tested in artificial snow precipitation were:

- Octagon Octaflo;
- Homeoil Safetemp;
- Clariant Safewing EG I 1996;
- Union Carbide ADF;
- Jarchem Jarkleer;
- Kilfrost DF Plus;

FIGURE 2.1

END CONDITION DATA FORM

NCAR SNOWMAKER

Winter 99/00

LOCATION: CEF-NRC (OTTAWA) **DATE:** **RUN # :** **STAND # :**

OAT: _____ °C

PRECIPITATION RATE: _____ g/dm²/hr

FLUID TEMPERATURE: _____ °C

FLUID QUANTITY APPLIED: _____ Litr/s

PLATE WASHING METHOD: _____

OTHER COMMENTS (Fluid Batch, etc):

_____

_____

_____

_____

_____

_____

_____

_____

	PRINT	SIGN
FAILURES CALLED BY :	_____	_____
HANDWRITTTEN BY :	_____	_____
LEADER :	_____	_____

*TIME (After Fluid Application) TO FAILURE FOR INDIVIDUAL CROSSHAIRS (hr:min)

Time of Fluid Application: _____ hr:min

FLUID NAME

B1 B2 B3			
C1 C2 C3			
D1 D2 D3			
E1 E2 E3			
F1 F2 F3			

CALCULATED FAILURE TIME (MINUTES) ☐

File h:\om1614\experiment\Snow_mak.xls
Af: Data Form Printed: 8/10/00

- Inland Duragly-P; and
- Octagon Octoflo EF.

The Type IV fluids tested in artificial snow precipitation were:

- UCAR Ultra + neat;
- Clariant MP 1957 neat;
- Clariant MP 1957 75/25 fluid/water concentration; and
- A reference fluid at standard concentration, Fluid X.

The reference fluid was prepared according to the following specifications:

Formula for Standard Fluid X

650 g	Ethylene Glycol
350 g	Deionized Water
6.0 g	Food Grade Xanthan Gum

Procedure:

1. Pour ethylene glycol into a container;
2. Slowly add the Food Grade Xanthan Gum while mixing;
3. Slowly add water while mixing; and
4. Agitate for at least 20 minutes, until a homogeneous mixture is obtained.

2.6 Personnel

One person from APS was required to conduct the indoor snow trials, with assistance from a second person to set up the system. The person poured the fluid, observed plate failures, and ran the snowmaking system. Assistance was required for changing the ice core and various maintenance activities.

Photo 2.1
Outside View of NRC Climatic Engineering Facility

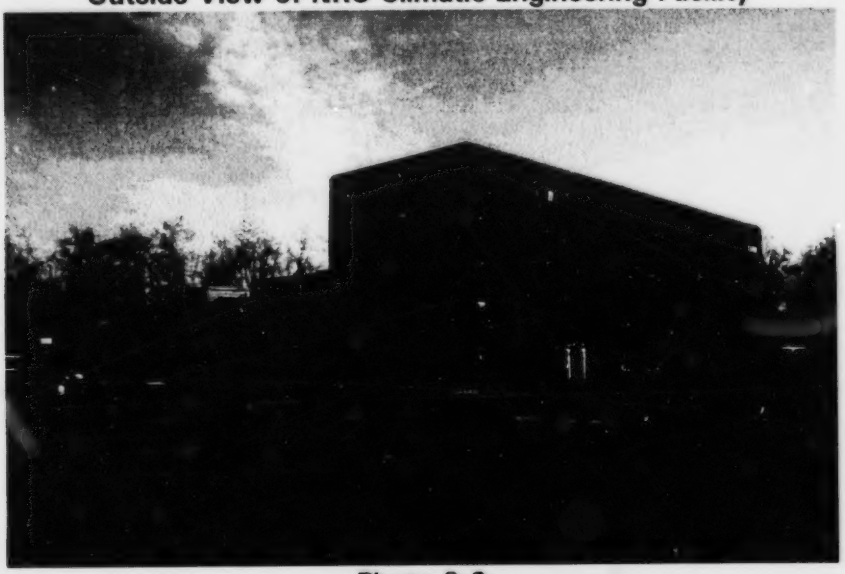
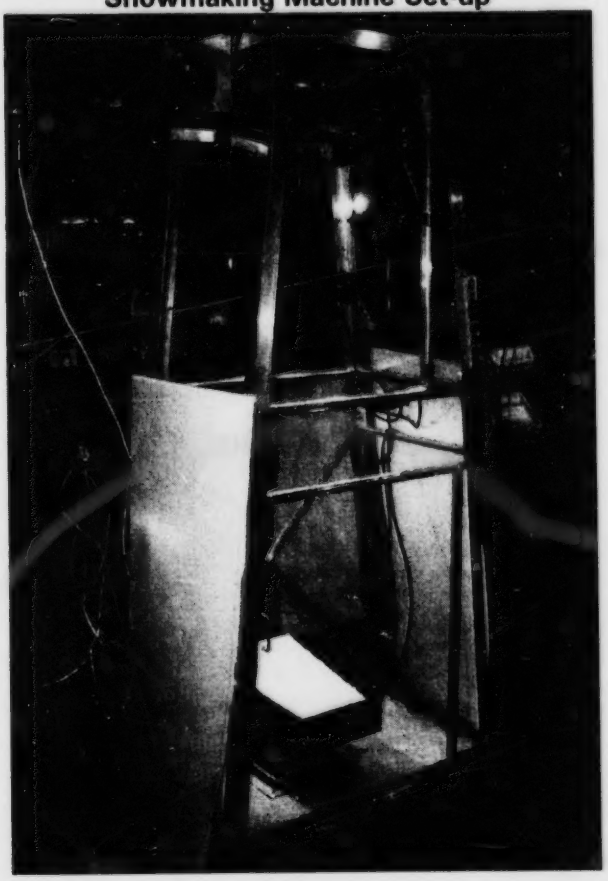


Photo 2.2
Snowmaking Machine Set-up



3. DESCRIPTION AND PROCESSING OF DATA

NCAR was tasked by the FAA and Transport Canada to provide a snow generation system. Due to delays in construction, the snowmaking machine delivered to APS Aviation in April 1999 was a development prototype and not a new system.

3.1 Artificial Snow Trial for Type IV Fluids

The NCAR snow machine was used to perform Type IV fluid holdover time tests in artificial snow conditions. The laboratory snowmaking system created the precipitation, and collected rate and temperature data. Four fluid concentration combinations were tested: a reference fluid at standard concentration, UCAR Ultra + neat (ethylene glycol fluid), Clariant MP 1957 neat (propylene glycol fluid), and Clariant MP 1957 75/25 fluid/water concentration (propylene glycol fluid).

Table 3.1 provides a log of all 24 Type IV tests with associated test conditions and failure times. Some trials were repeated due to the malfunction of equipment, such as the weigh scale freezing or the ice core breaking. Trials were also repeated to ensure reproducibility.

The failure times recorded from the flat plate trials were used to create a regression curve for each fluid tested. The curves are best-fit power law regression curves based on all available data points for each fluid in each temperature range. Holdover times were generated from these curves at precipitation rates of 10 and 25 g/dm^2/hr.

3.2 Artificial Snow Trial for Type I Fluids

Type I fluid holdover time tests in artificial snow conditions were also performed using the NCAR snowmaking system to create the precipitation and to collect rate and temperature data; eight fluids (see Section 2.5) were diluted to a 10°C buffer below ambient temperature.

Table 3.2 provides a log of all Type I tests with associated test conditions and failure times. The tests scheduled at colder ambient temperatures were cancelled because of equipment malfunction. At temperatures below -20°C, the snowmaking machine was not always capable of producing precipitation. A total of 40 tests were conducted in artificial snow with Type I fluid.

The precipitation rate and the total snow accumulation during each trial were recorded by the weigh scale and logged to a data file. A chart representing the accumulation of precipitation as a function of test time for each of the

TABLE 3.1

TYPE IV HOLDOVER TIME TEST - ARTIFICIAL SNOW (NCAR) AT CEF-NRC FOR 1998/99

Test #	Run #	Fluid	Concentration	Temperature (°C)	Total Snow Mass (g)	Total Test Time (hr)	Average Snow Rate (g/dm2/hr)	Failure Time (min.)
1	5	Fluid X	Neat	-10.0	134	0.83	9.5	52
2	6	Fluid X	Neat	-10.0	127	0.78	9.7	47
3	7	Fluid X	Neat	-10.2	179	0.45	23.6	27
4	7a	Fluid X	Neat	-13.4	182	0.38	28.2	23
5	7b	Fluid X	Neat	-13.6	214	0.52	24.6	31
6	8	Fluid X	Neat	-14.4	166	0.35	28.1	21
7	9	Fluid X	Neat	-25.1	120	0.65	10.9	45
8	11	Fluid X	Neat	-25.4	131	0.34	23.2	22
9	21	Ucar Ultra+	Neat	-10.1	139	0.64	13.0	41
10	22	Ucar Ultra+	Neat	-10.1	146	0.78	11.2	47
11	23	Ucar Ultra+	Neat	-10.2	160	0.32	30.2	22
12	23a	Ucar Ultra+	Neat	-13.8	199	0.49	24.2	29
13	24	Ucar Ultra+	Neat	-10.0	132	0.33	23.7	22
14	25	Ucar Ultra+	Neat	-25.6	147	0.78	11.2	48
15	26	Ucar Ultra+	Neat	-25.4	156	0.82	11.3	51
16	27	Ucar Ultra+	Neat	-25.7	166	0.48	20.5	31
17	45	Clariant Safewing 1957	Neat	-14.0	72	0.38	11.2	26
18	46	Clariant Safewing 1957	Neat	-13.4	88	0.46	11.3	28
19	47	Clariant Safewing 1957	Neat	-13.7	67	0.14	28.0	9.1
20	48	Clariant Safewing 1957	Neat	-13.8	80	0.16	30.2	9.6
21	49	Clariant Safewing 1957	75/25	-13.8	74	0.43	10.3	26
22	50	Clariant Safewing 1957	75/25	-13.5	47	0.26	10.9	17
23	51	Clariant Safewing 1957	75/25	-13.8	39	0.09	26.4	5.3
24	52	Clariant Safewing 1957	75/25	-13.9	55	0.15	22.2	10

Note: The total test time is the duration of time during which rate data are available.

TABLE 3.2
TYPE I HOLDOVER TIME TEST - ARTIFICIAL SNOW (NCAR) AT CEF-NRC FOR 1998/99

Test No.	Date	Start Time (Local)	End Time (Local)	Fluid Name	Fluid Dilution	fail time [min.]	Rate of precep. [g/dm²/hr]	Chamber Temp (°C)	comments
1	Jul-19-99	12:17:15	12:23:13	UCAR ADF	-45	6.0	18.1	-35.8	Test Discarded
2	Jul-19-99	12:33:54	12:39:54	HOMEOIL SAFETEMP	-45	6.0	11.4	-35.9	Test Discarded
3	Jul-19-99	18:35:37	18:39:00	UCAR ADF	-45	3.4	23.1	-31.0	Test Discarded
4	Jul-20-99	18:51:08	18:53:55	OCTAFLO	-20	2.8	24.2	-10.0	
5	Jul-20-99	8:28:45	8:31:27	HOMEOIL SAFETEMP	-20	2.7	23.3	-10.0	
6	Jul-21-99	8:34:22	8:37:34	JAR KLEER	-20	3.2	13.7	-10.2	
7	Jul-21-99	8:40:52	8:44:06	KILFROST DF PLUS	-20	3.2	24.3	-10.2	
8	Jul-21-99	8:46:41	8:50:05	CLARIANT SAFEWING EG I 1996	-20	3.4	20.8	-10.2	
9	Jul-21-99	8:52:40	8:56:47	INLAND DURAGLY-P	-20	4.1	N/A	-10.2	
10	Jul-21-99	9:06:50	9:12:50	UCAR ADF	-20	6.0	4.5	-10.0	
11	Jul-21-99	9:28:31	9:33:40	OCTAFLO	-20	5.2	N/A	-9.9	
12	Jul-21-99	10:07:08	10:11:39	HOMEOIL SAFETEMP	-20	4.5	6.9	-10.0	
13	Jul-21-99	10:19:09	10:24:08	OCTAFLOW EF	-20	5.0	N/A	-10.0	
14	Jul-21-99	10:33:59	10:38:03	JAR KLEER	-20	4.1	9.0	-10.2	
15	Jul-21-99	10:45:44	10:49:25	CLARIANT SAFEWING EG I 1996	-20	3.7	N/A	-10.3	
16	Jul-21-99	11:01:50	11:05:48	INLAND DURAGLY-P	-20	4.0	9.9	-10.7	
17	Jul-21-99	11:11:09	11:15:07	KILFROST DF PLUS	-20	4.0	11.4	-10.7	
18	Jul-21-99	11:49:10	11:51:52	UCAR ADF	-20	2.7	26.6	-10.7	
19	Jul-21-99	11:59:59	12:02:30	OCTAFLO	-20	2.5	18.6	-10.7	
20	Jul-21-99	12:06:24	12:10:11	OCTAFLOW EF	-20	3.8	18.6	-10.6	
21	Jul-21-99	12:17:04	12:20:04	CLARIANT SAFEWING EG I 1996	-20	3.0	18.1	-10.7	
22	Jul-21-99	12:28:42	12:32:32	HOMEOIL SAFETEMP	-20	3.8	16.3	-10.6	
23	Jul-21-99	12:37:59	12:41:14	JAR KLEER	-20	3.3	18.6	-10.6	
24	Jul-21-99	12:47:44	12:51:09	INLAND DURAGLY-P	-20	3.4	16.2	-10.6	
25	Jul-21-99	12:58:39	13:02:15	KILFROST DF PLUS	-20	3.6	13.7	-10.7	
26	Jul-21-99	13:23:50	13:26:32	UCAR ADF	-20	2.7	24.4	-10.7	
27	Jul-21-99	14:29:14	14:31:54	UCAR ADF	-20	2.7	26.8	-10.6	
28	Jul-21-99	14:39:12	14:41:56	OCTAFLO	-20	2.7	29.2	-10.6	
29	Jul-21-99	14:47:25	14:50:06	HOMEOIL SAFETEMP	-20	2.7	41.6	-10.6	
30	Jul-21-99	14:56:48	14:59:36	JAR KLEER	-20	2.8	13.2	-10.6	
31	Jul-21-99	15:08:59	15:12:09	CLARIANT SAFEWING EG I 1996	-20	3.2	18.2	-10.6	
32	Jul-21-99	15:16:22	15:19:05	KILFROST DF PLUS	-20	2.7	27.6	-10.5	
33	Jul-21-99	15:24:53	15:27:45	INLAND DURAGLY-P	-20	2.9	N/A	-10.5	
34	Jul-21-99	15:43:08	15:45:57	INLAND DURAGLY-P	-20	2.8	23.7	-10.5	
35	Jul-21-99	15:51:50	15:54:28	OCTAFLOW EF	-20	2.6	22.7	-10.6	
36	Jul-21-99	16:16:10	16:18:54	JAR KLEER	-20	2.7	15.9	-10.7	
37	Jul-21-99	16:30:56	16:33:23	JAR KLEER	-20	2.5	N/A	-10.6	
38	Jul-21-99	16:50:03	16:52:35	JAR KLEER	-20	2.5	18.9	-10.6	
39	Jul-21-99	16:58:29	17:01:03	HOMEOIL SAFETEMP	-20	2.6	24.2	-10.7	
40	Jul-21-99	17:05:58	17:08:19	CLARIANT SAFEWING EG I 1996	-20	2.4	N/A	-10.7	

Note: N/A indicates not available.

Type I trials is included in Appendix C. Some data points at the start and end of tests were excluded from the average rate calculations because of their inconsistency with the general shape of the accumulation curves. The two vertical lines show the upper and lower accumulation limits considered in calculating the rate.

4. ANALYSIS AND OBSERVATIONS

This section outlines the observations made during the trials and presents discussions of the experimental data collected in comparison with data from natural snow trials.

4.1 Artificial Snow Trial for Type IV Fluids

The initial comments recorded by the test observers during the Type IV trials include the following:

- The snowflake size is larger than that observed in natural precipitation;
- The distribution of precipitation is not always consistent; some sections of the test plate receive more snow;
- The ice core occasionally cracks or breaks, and pieces of ice fall on the test plate; and
- The plates fail very rapidly under artificial snow.

The flakes produced by the snowmaker are ice shavings cut from a long ice core. Based on visual observation, the flakes are, on average, larger than those found in nature. This type of precipitation could have an increased tendency to dilute the fluid at localized points.

Snow bridging occurred frequently, possibly attributable to flakes larger than those of natural snow. Because of precipitation dimensions, a reduced percentage of the fallen precipitation is in contact with the fluid film. The remainder of the precipitation that falls on the plate surface forms a snow bridge that is suspended above the fluid. The fluid film must absorb the lower levels of precipitation before the remaining flakes can be absorbed. The snow accumulates more quickly than the quantity of precipitation being absorbed by the fluid. The localized fluid dilution due to larger flakes reduces the effectiveness of anti-icing fluid at these points. A combination of these two effects reduces the time to fluid failure.

The data analysis indicates that the Type IV failure times were up to 68% shorter for the trials performed with the snowmaking system when compared to the natural snow failure times.

The indoor snow test results were compared to the holdover time graphs, which are based on natural snow tests. The results are shown in Figures 4.1 to 4.4. The failure times during the artificial snow trials were significantly shorter than the times observed during natural snow trials.

The holdover times calculated from the indoor snow regression curves for each fluid are displayed in Table 4.1 along with the fluid specific holdover times published in the TDC report, TP 13477E (1).

Figure 4.1 shows the reference fluid, Fluid X, holdover time graph. The upper curves represent regression curves generated from the outdoor data collected during the 1998-99 test season. The lower curves represent a similar regression analysis performed with the data collected from the trials at the NRC test facility. The curve generated from the -25°C data is not expected to cross the -10 to -14°C curve. The error on the lower temperature curve is partially due to the lack of data points, because only two tests were performed at that ambient temperature.

Holdover time trials were performed with the Type IV propylene glycol-based fluid, Clariant 1957. The failure times from the artificial snow trial were much shorter than those of the natural snow trial for both dilutions tested. The artificial snow trials were performed only at -16°C because of the late arrival of the snowmaking system.

The failure calls for the ethylene-based Fluid X and all propylene-based fluids occurred much more quickly during the artificial snow trials than during the natural snow trials. In many cases, the artificial snow caused failure times in the order of half the time observed during natural snow precipitation. The nature of artificial snow creates large safety factors and would reduce the holdover times to less than half of their present values. The differences between natural and artificial snow need to be reconciled.

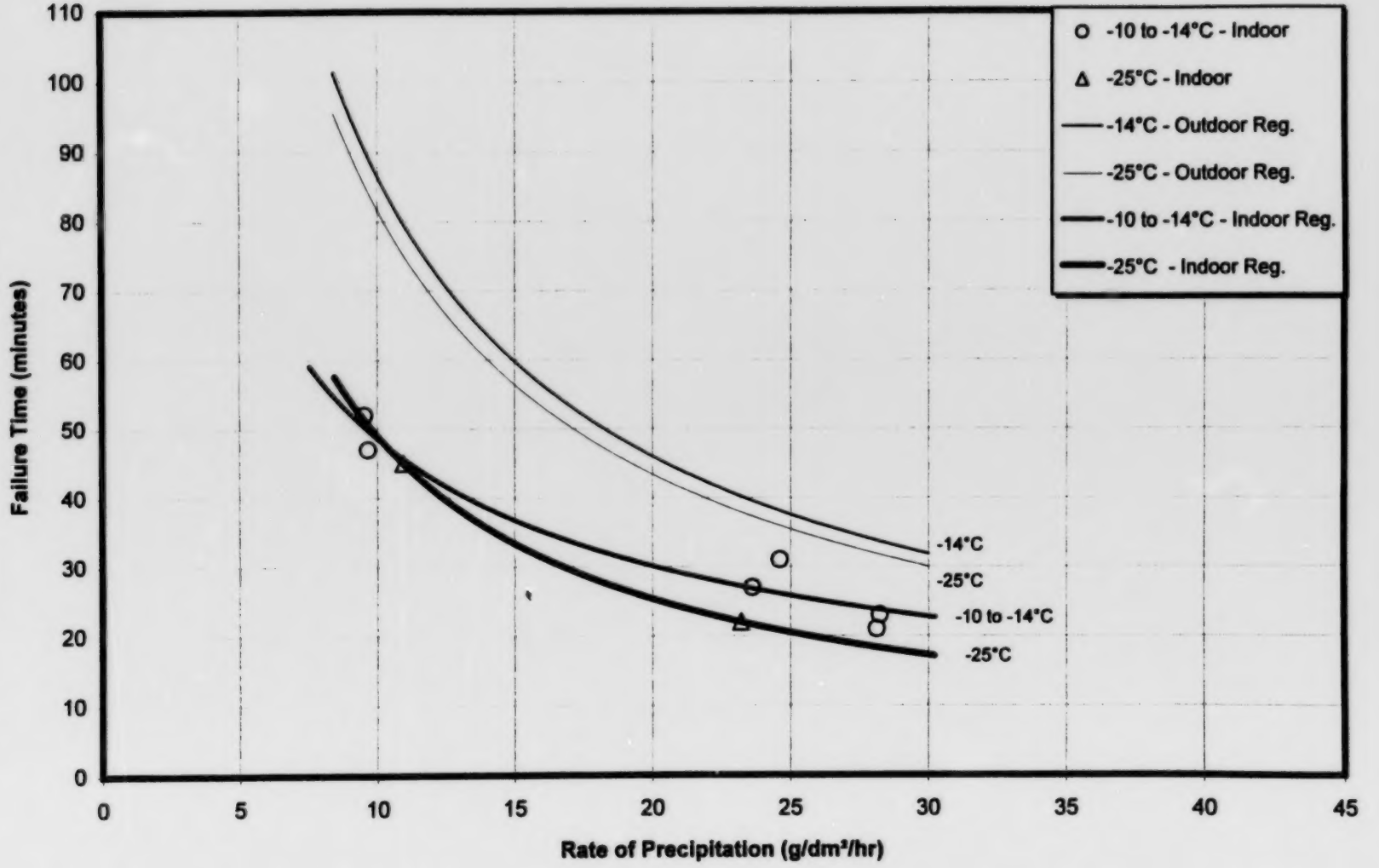
The ethylene-based fluid ULTRA+ did not exhibit such large variations between the artificial snow trials and the natural snow trials. The fluid did, however, fail more rapidly during the artificial snow trial. The difference between the natural snow regression-curves and the artificial snow regression curves is in the order of 10 to 15%. A significant difference between this fluid and the others is the flake acceptance demonstrated by Ultra+. In all temperatures and precipitation conditions tested, Ultra+ easily accepted contamination within the fluid matrix.

The plate temperature traces, recorded during indoor snow trials, exhibited large drops in temperature during some trials. Further analysis would be required to compare temperature traces from natural and artificial snow trials. The impact of lower plate temperatures on the holdover times would also require investigation.

FIGURE 4.1

ARTIFICIAL SNOW DATA vs OUTDOOR DATA

FLUID X

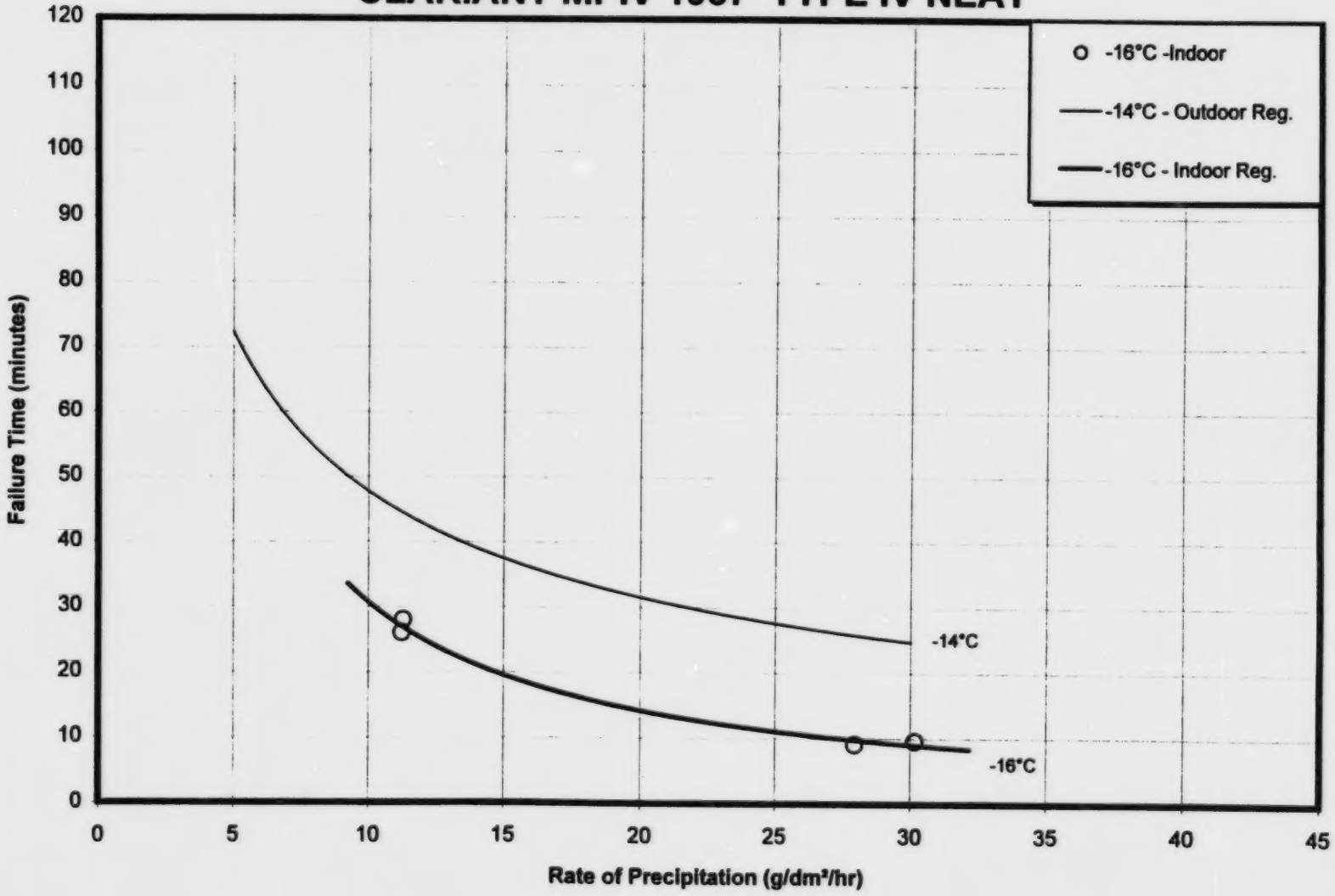


cm1514/report/ncar/Ncar_hot.xls
At: Fluid X
8/10/00, 7:58 PM

FIGURE 4.2

ARTIFICIAL SNOW DATA vs OUTDOOR DATA

CLARIANT MPIV 1957 TYPE IV NEAT

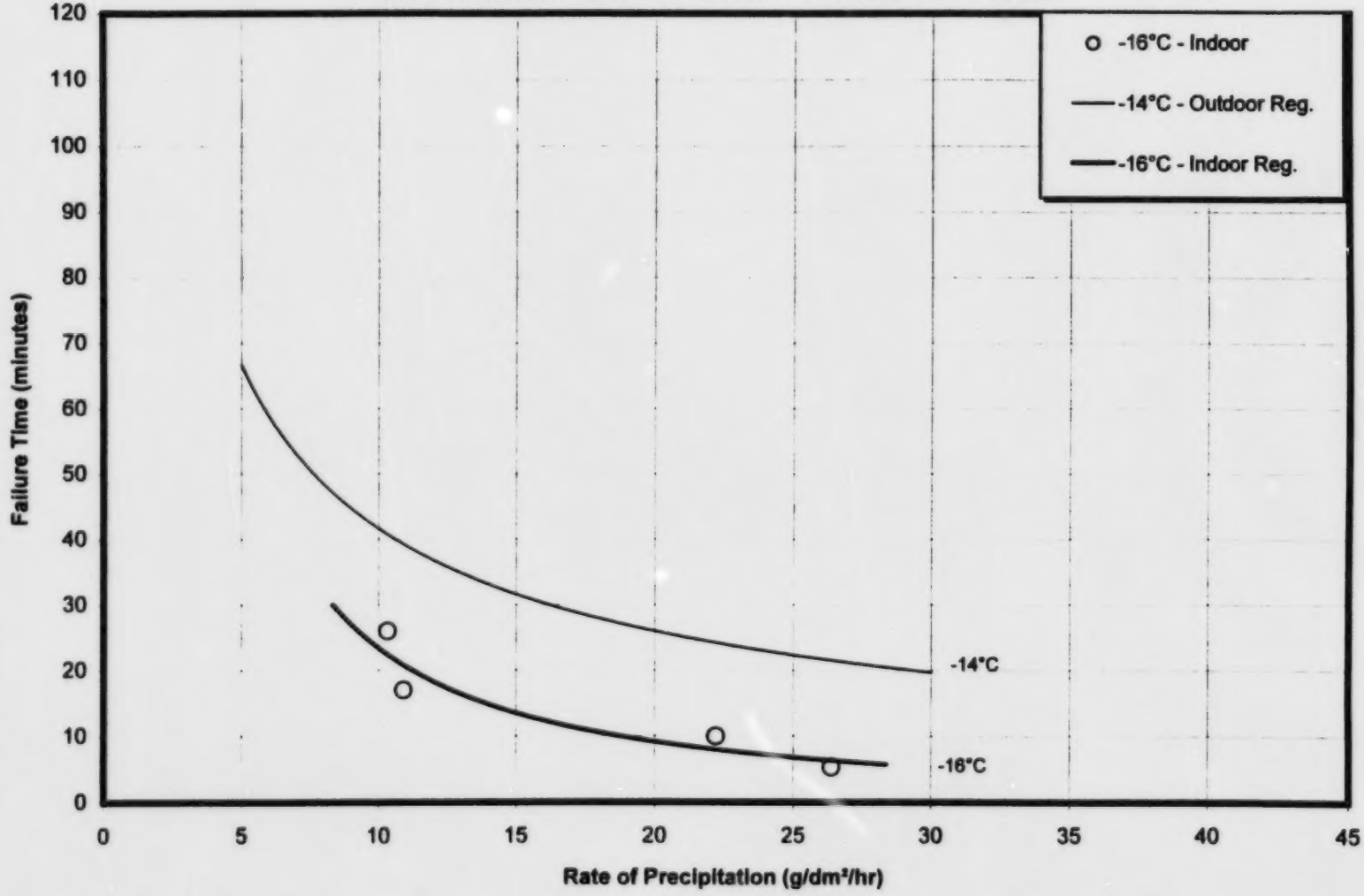


cm1514/report/ncar/Ncar_hot
AE C 1957 100
11/26/99, 10:51 AM

FIGURE 4.3

ARTIFICIAL SNOW DATA vs OUTDOOR DATA

CLARIANT MPIV 1957 TYPE IV 75/25

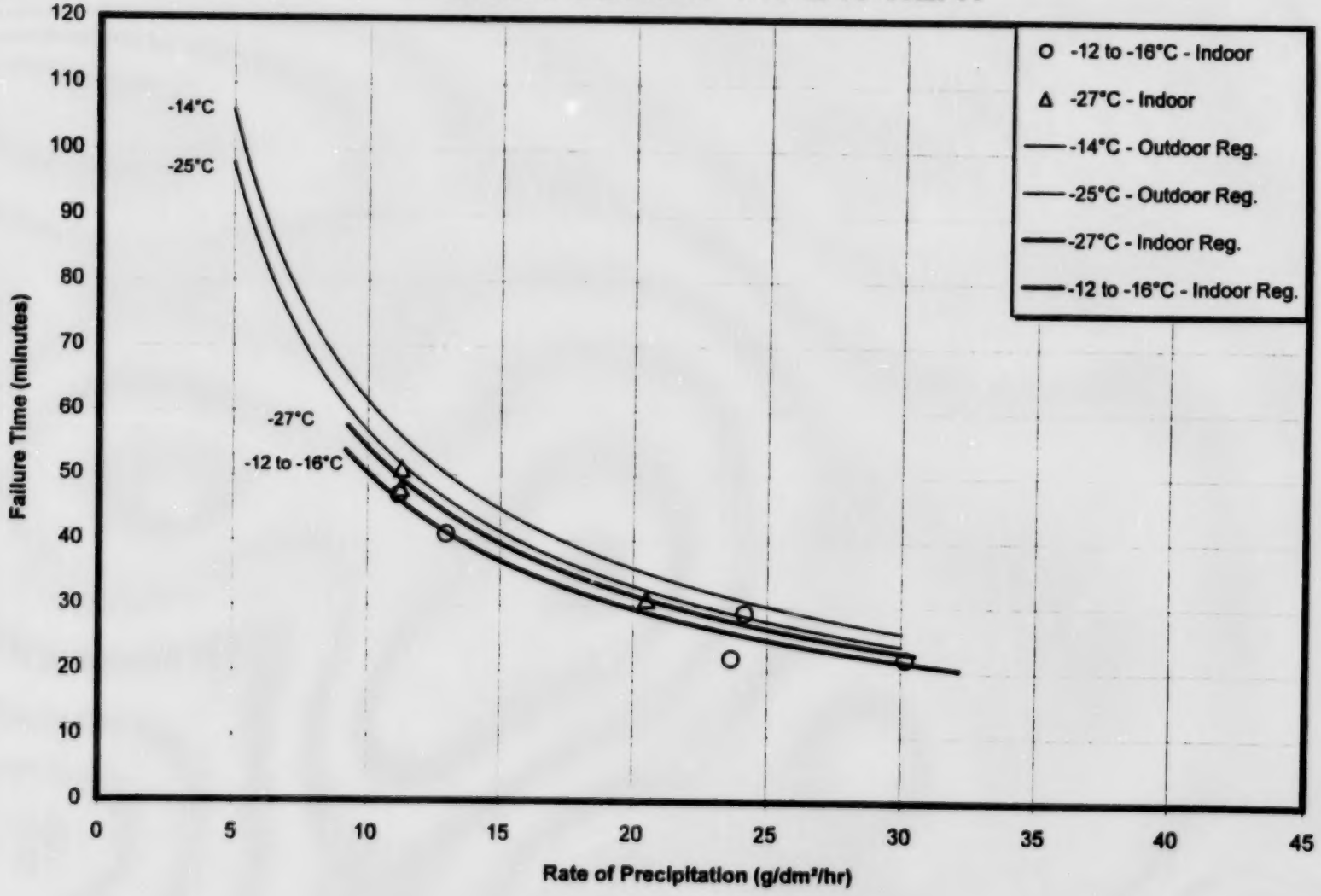


cm1514/report/ncar/fncar_hot
At: C1957 75
11/26/99, 10:52 AM

FIGURE 4.4

ARTIFICIAL SNOW DATA vs OUTDOOR DATA

UCAR ULTRA+ TYPE IV NEAT



cm1514\report\ucar\Ncar_hot
At: Ultra +
11/26/99, 10:50 AM

TABLE 4.1

HOLDOVER TIME COMPARISON OF ARTIFICIAL vs. NATURAL SNOW

Fluid	Concentration	Temperature (°C)	Natural Snow Times (min)	Artificial Snow Times (min)	SAE HOT (min)
Fluid X	Std	-25	35 to 82	26 to 49	N/A
Fluid X	Std	-14	38 to 86	20 to 49	N/A
Ucar Ultra+	Neat	-25	28 to 57	27 to 54	20 to 45
Ucar Ultra+	Neat	-14	30 to 62	25 to 50	25 to 55
Clariant Safewing 1957	Neat	-14	28 to 48	11 to 31	30 to 50
Clariant Safewing 1957	75/25	-14	22 to 42	7 to 23	20 to 40

cm1514/report/ncar/HOT Summary
14/08/00, 1:16 PM

4.2 Artificial Snow Trial for Type I Fluids

Most of the Type I fluids tested were new fluids that had not been used before in holdover time tests. It is not possible, therefore, to compare fluid specific indoor tests to fluid specific outdoor tests. The results of the indoor Type I testing can be compared, however, to the standard SAE holdover times for Type I fluids.

Figure 4.5 shows the holdover time graph for all trials completed with the snowmaking system during the summer of 1999. The currently accepted SAE holdover times are also included. When comparing the indoor snow data to the holdover time values, a very large discrepancy is noticed. At a precipitation rate of 10 g/dm^2/hr, the SAE time is 15 minutes; the artificial snow failure times are around 4 minutes. This represents a reduction of 73% of the original holdover time. At a precipitation rate of 25 g/dm^2/hr, the current holdover time is 6 minutes; the artificial snow failure times are around 3 minutes.

The holdover times shown in Figure 4.5 are based on test data collected during the 1994-95 test season and previous test seasons. Trials were conducted with a standard concentration fluid that was not diluted to a 10°C buffer prior to the 1994-95 season. The times were established by observing the complete data set without the use of regression analysis or defined rate limits. Test procedures have become more stringent, and failure calls have become more consistent since these holdover times were established. To increase consistency, failure calls have recently been made by the same observer.

Figure 4.6 shows the outdoor data points from the 1994-95 test season used to substantiate the present SAE holdover time values. The data scatter is more significant in the old outdoor test data. Some data points collected during the 1994-95 test season were below the holdover times. At that time, the SAE G12 holdover time sub-committee collectively decided to keep the holdover time range at 6 to 15 minutes. Many of the points that fell below the lower limit were considered close to the limit or had occurred under extreme weather conditions.

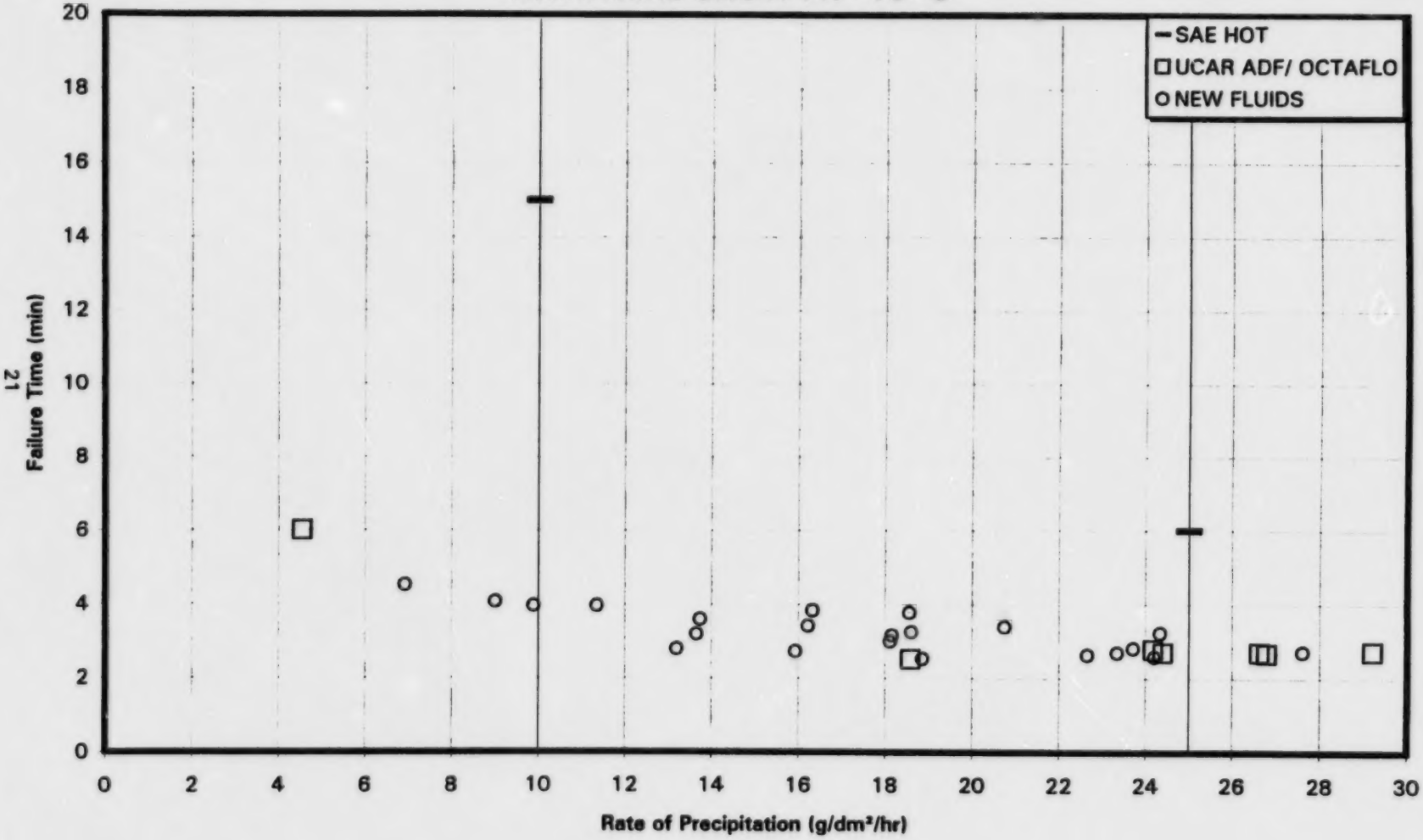
According to Figure 4.6, higher wind speeds can cause longer failure times because the fluid could be maintained on the plate surface by the wind. Since the indoor snow trials were performed in a controlled environment, no winds were present, which could have contributed to quicker failure progressions during the indoor trials. On the other hand, higher winds contribute to more heat loss from the deicing fluid and can produce a more significant drying effect on top of the fluid surface. The relative humidity of the surrounding environment can contribute to variations in the fluid

FIGURE 4.5

EFFECT OF RATE OF PRECIPITATION ON ENDURANCE TIME

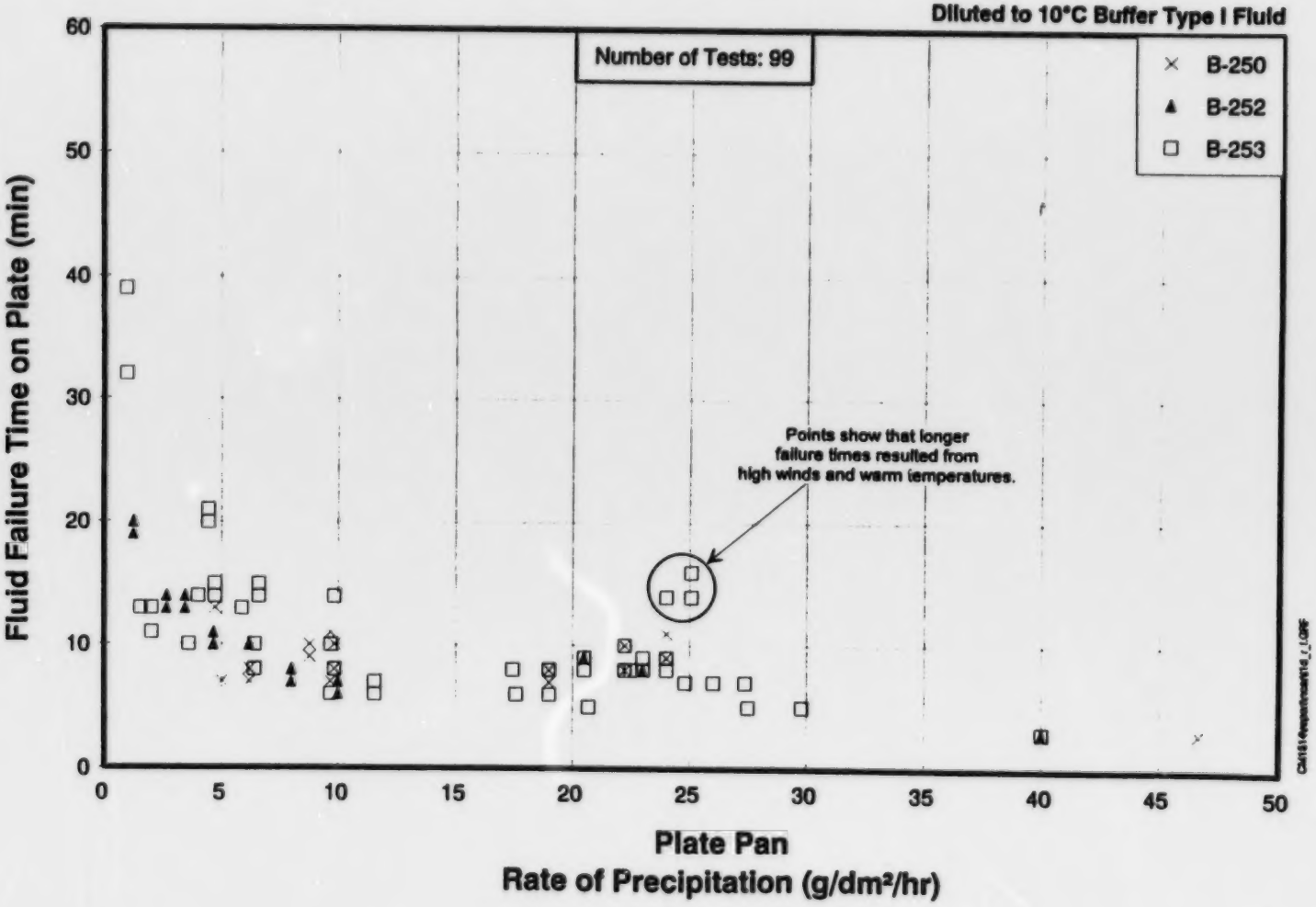
TYPE I DEICING FLUIDS

ARTIFICIAL SNOW AT -10°C



cm1514/report/ncar/Typ1_all.xls
At: SNOW
10/28/99, 3:49 PM

FIGURE 4.6
EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON
DILUTED (10°C BUFFER) TYPE I FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS



evaporation rate and, in some circumstances, could accelerate the onset of failure and the failure progression.

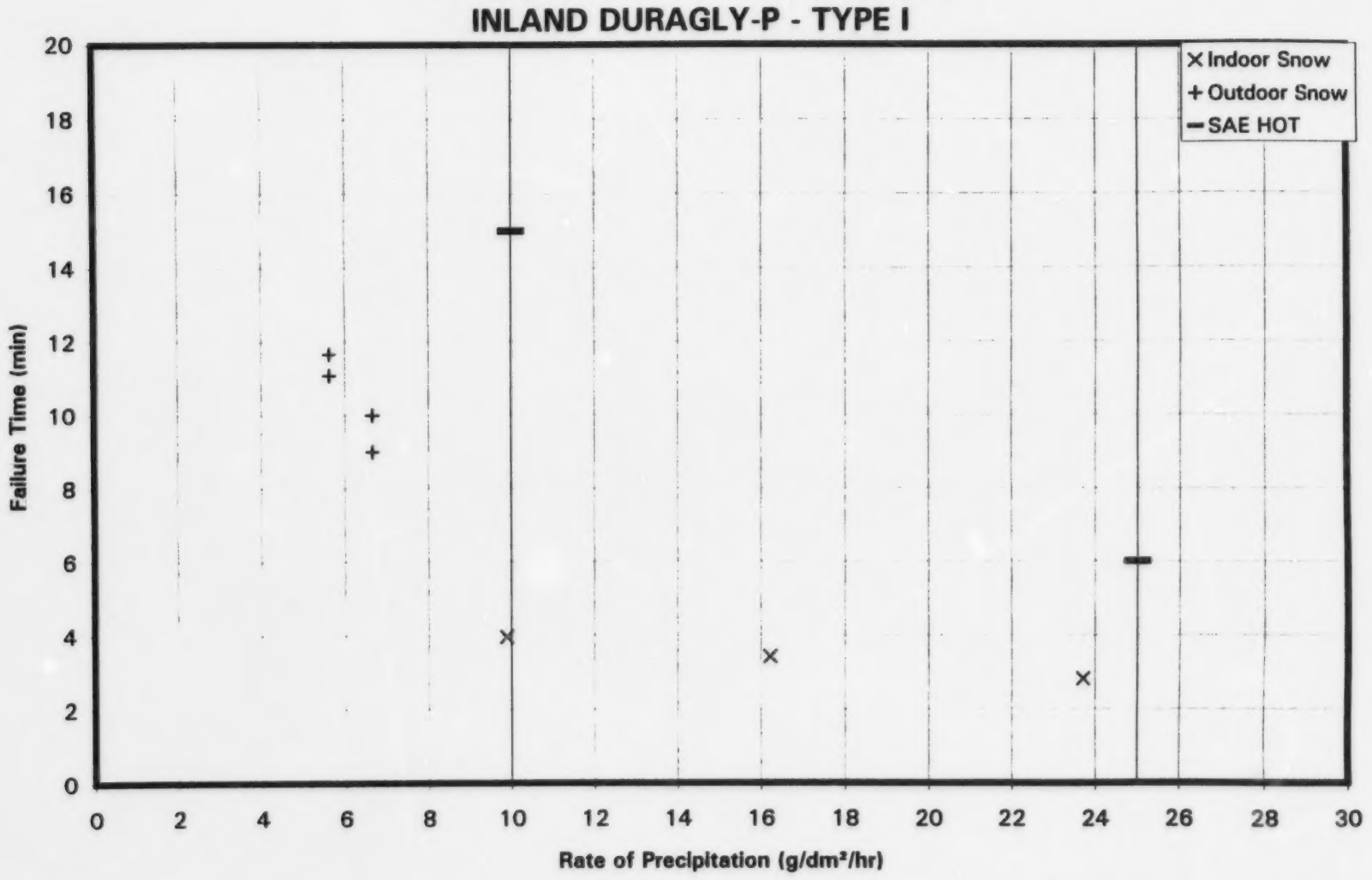
The nature of the artificial precipitation creates difficulties in making failure calls that are consistent with natural snow failure calls. The larger flakes created from ice-core shavings have a tendency to dissolve more slowly than natural snow and cause the fluid film to dry near the flakes. Shorter failure times can result from the artificial snowflakes bridging above the thin fluid layer. Due to this behaviour, failure calls occur when good fluid remains on the plate surface.

A small number of Type I tests were conducted in natural precipitation conditions during the 1998-99 test season. These tests were performed according to the currently established APS test procedures, and experienced observers made the failure calls. Figure 4.7 shows the failure times recorded for the natural snow trials and for indoor snow trials for the Inland Duragly-P propylene Type I fluid.

The natural snow failures occurred before the SAE holdover times for every test conducted with the Duragly-P fluid. Because the precipitation rates for the natural snow tests are lower than for artificial snow tests, it is expected that failures would occur after the artificial snow failures. From Figure 4.7 it can be observed that this was the case, however, the failure times are two or three time longer than the artificial snow tests. Due to the nature of the snow produced by the snowmaking system, the gap between these failure times is larger than expected.

FIGURE 4.7

EFFECT OF RATE OF PRECIPITATION ON ENDURANCE TIME



cm1514/report/ncar/Recy_net
At: Snow
11/26/99, 10:43 AM

4.3 Rate and Snow Mass Scatter

The precipitation rate and the total snow mass accumulated on the plate are displayed in near real time by the system software and logged to the data file. The precipitation rate is calculated on regular intervals based on the weight of snow that has fallen on a given area during a given amount of time.

The scale under the plate and collection bucket assembly records the weight and sends the data to the system software. Appendix C shows the graphs of the snow mass accumulation for each of the Type I trials. During some of the trials performed on Type I fluids, the snow mass progression did not follow the expected behaviour. Figure 4.8 shows the snow mass versus time graphs for four separate trials.

Forms 1 and 2 represent the standard snow mass progression observed when artificial snow falls on the plate. The total weight increases linearly from the start to the end of the test. A quick increase in weight can be observed at the start of a trial if the fluid has not been completely poured before the data logging was started. A small amount of scatter is expected in the snow mass, because the scale can fluctuate due to surrounding conditions.

Problems were noted in the mass and rate logging systems. When snow accumulates, the scale has a tendency to freeze and no mass data can be recorded. The data recorded on Form 11 is incorrect. The trace indicates that the snow mass would have increased from nearly 0 kg to 500 kg in less than 5.5 minutes. During some trials snow accumulated within the scale assembly, and the results of those trials are inconclusive.

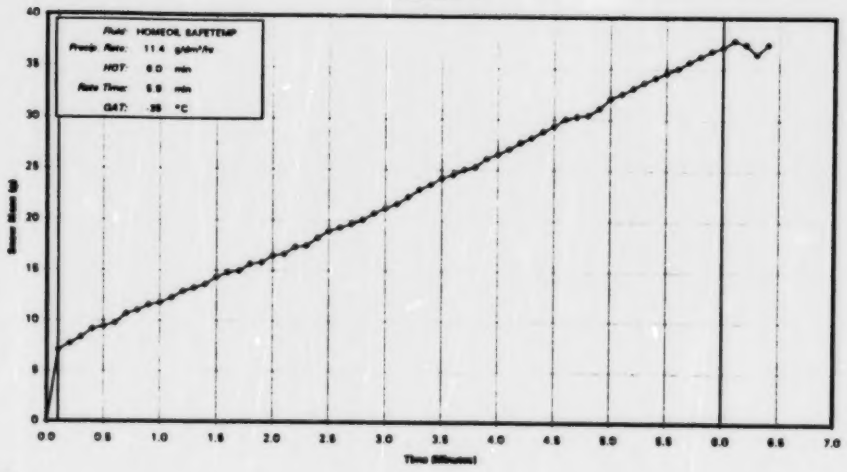
Form 21 shows a result that occurred during many tests. The mass of the plate and collection bucket assembly should not decrease at any time during the trials. However, the total weight dropped drastically during the first minute of the test shown.

FIGURE 4.8

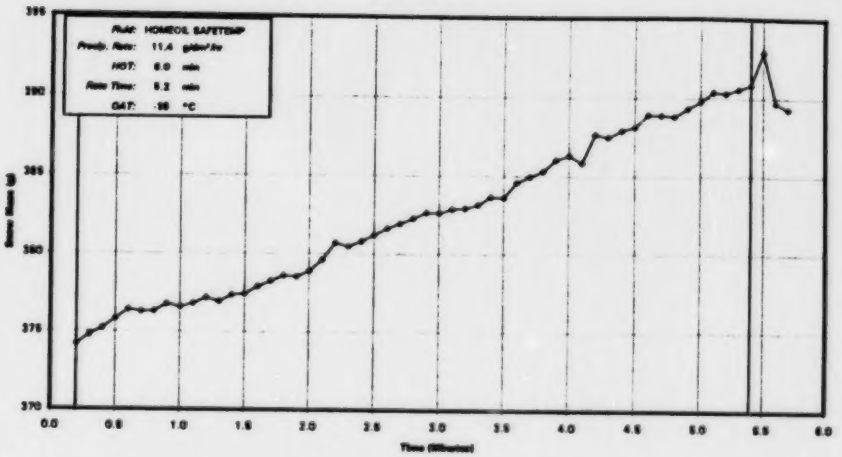
SNOW MASS ACCUMULATION

NCAR SNOW MAKER

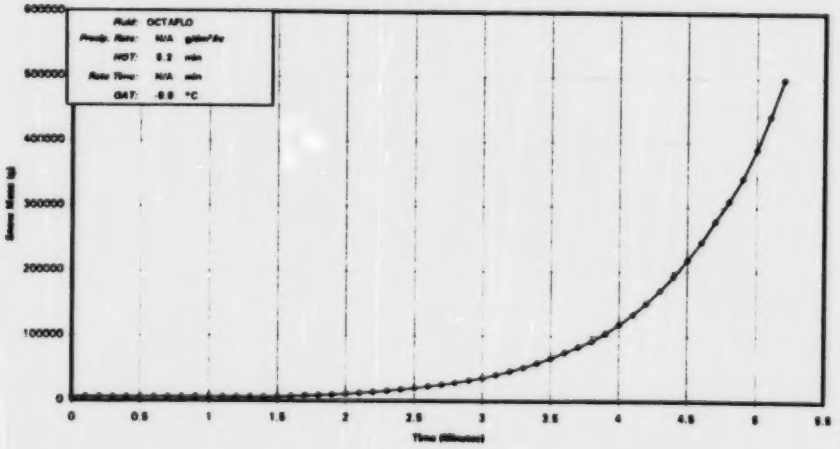
FORM # 1



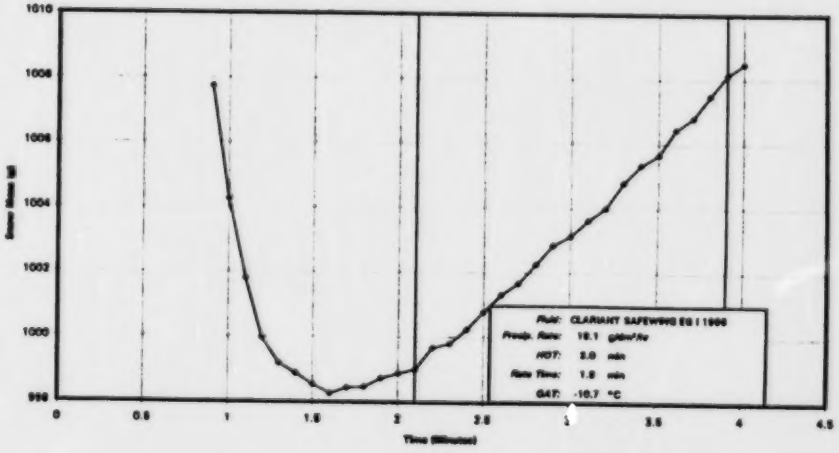
FORM # 2



FORM # 11



FORM # 21



4.4 Snowmaker Functionality

The observations made during the holdover time trials performed using the snowmaking system led to the creation of a list of functionality issues. Many suggestions were made to improve the present system. A list, shown in Appendix E, was compiled and sent to both NCAR and the FAA. This section discusses in more detail reasons behind some of these suggestions.

The snowmaking machine does not always function at very cold temperatures. When trials were attempted to test Type I fluids at their lowest operating temperatures, between -25°C and -35°C, the machine froze. The delivered prototype is not capable of operating in the temperature range required to test fluids at their lowest operating temperature.

Snow distribution is not always consistent; some areas of the plate may receive more snow than others. Fans that blow the shredded ice-core particles upward control the snow pattern. It is possible to change the pattern by rotating the fans, but this does not always produce even snow distribution. The scale and collection plate assembly must be placed in the centre of the machine's chamber, according to the present design. It would be beneficial if the assembly could be placed anywhere in the chamber to obtain the best possible distribution. Additional fans could be added to the system.

The software requires some modifications to the rate logging and start time triggering. According to the current design, the NCAR snowmaker software begins logging the temperatures, scale readings, and precipitation rates when the ice-core translator is started in the forward direction. Because the precipitation must begin before the fluid is poured, the start of a trial is ambiguous in the data file. A button, which would send a test start or test end comment to the data file, should be added to the user interface to facilitate the post test data analysis.

The rate logging should be modified to include an average rate for the entire test period. The current system logs the precipitation rate at given time intervals. The average rate for the test is required for the holdover time analysis. According to the current configuration, data manipulation is required to obtain this rate. An average rate from test start to present time should also be included in the user interface.

Other modifications should be made to the snowmaker system so that trials could be conducted according to the proposed SAE procedure. This procedure dictates that the plate must first be cleaned with ethanol or methanol. The fluid would then be poured, and the plate would be allowed to sit for 5 minutes before the test is started.

Additional improvements required include a rate compensation function that would allow the snowmaker to recalibrate the drill and translator speeds to precisely obtain the set precipitation rate. The plate and collection bucket assembly should be modified so that testers could remove the plate for cleaning.

5. CONCLUSIONS

Artificial snow produced by the prototype snowmaker exhibited significant differences from natural snow. The failure times observed for both Type I and Type IV fluids were much shorter than the holdover times published in the SAE tables. The appearance of the failures and the precipitation conditions also deviated from those of natural snow.

To obtain correct data on precipitation accumulation for all trials, modifications to the system are required, particularly to the rate logging and the weigh scale assembly.

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6. RECOMMENDATIONS

An extensive list of suggestions (see Appendix E) was compiled and sent to NCAR with the hope that they would be incorporated into the final delivery model that will replace the prototype version of the snowmaking machine. The system should be tested to ensure the new snowmaking machine's functionality.

New fluids should be tested with the updated system to compare holdover times at several temperatures and with several dilutions. Both propylene-glycol and ethylene-glycol based fluids should be included.

It is also recommended that further testing be performed to compare fluid failure times of artificial snow vs. natural snow. All test variables (such as ambient temperature, plate temperature, relative humidity, and precipitation rates) should be recorded in natural snow trials and duplicated during indoor snow trials. Further trials should be designed to reconcile the differences between natural and artificial snow.

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REFERENCE

1. Chaput, M., Hanna, M., Peters, A., Hunt, M., Ruggi, E., *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1998-99 Winter*, APS Aviation Inc., Montreal, October 1999, Transportation Development Centre report, TP 13477E, 278.

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APPENDIX A

WORK STATEMENT

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 98/99

(December 1998)

1. INTRODUCTION

Following the crash of a F-28 at Dryden in 1989 and the subsequent recommendations of the Commission of Inquiry, the Dryden Commission Implementation Project (DCIP) of Transport Canada (TC) was set up. Together with many other regulatory activities an intensive research program of field testing of deicing and anti-icing fluids was initiated with guidance from the international air transport sector through the Society of Automotive Engineering (SAE) G-12 Committee on Aircraft Ground De/Anti-icing. As a result of the work performed to date Transport Canada and the US Federal Aviation Administration (the FAA) have been introducing holdover time regulations and the FAA has requested that the SAE, continue its work on substantiating the existing ISO/AEA/SAE Holdover Time (HOT) tables (TC research representing the bulk of the testing).

The times given in HOT Tables were originally established by the Association of European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted initially by the DCIP R&D Task Group and subsequently by its successor Transport Canada, Transportation Development Centre (TDC) Aviation Winter Operations R&D (AWORD) Group has been to determine the performance of fluids on standard flat plates in order to substantiate the times or, if warranted, to recommend changes.

TDC has undertaken most of the field research and much other allied research to improve understanding of the fluid HoldOver Times. Most of the HOT table cells been substantiated, however low temperatures have not been adequately explored and further tests are needed.

The development of ULTRA by Union Carbide stimulated all the fluid manufacturers to produce new long lasting anti-icing fluids defined as Type IV. All the Type IV fluids were upgraded in early 1996 and therefore all table conditions need to be re-evaluated and the table revised if necessary. Certain special conditions for which advance planning is particularly difficult such as low temperatures with precipitation, rain or other precipitation on cold soaked surfaces, and precipitation rates as high as 25 gm/dm²/hr need to be included in the data set. All lead to the need for further research.

Although the Holdover tables are widely used in the industry as guides to operating aircraft in winter precipitation the significance of the range of time values given in each cell of the table is obscure. There is a clear need to improve the understanding of the limiting weather conditions to which these values relate.

An important effort was made in the 94/95 and 95/96 seasons to verify that the flat plate data were representative of aircraft wings. Airlines cooperated with DCIP by making aircraft and ground support staff available at night to facilitate the correlation testing of flat plates with performance of fluids on aircraft. An extension of this testing was to observe patterns of fluid failure on aircraft in order to provide data to assist pilots with visual determination of fluid failure, and to provide a data to contamination sensor manufacturers. The few aircraft tests made to validate the flat plate tests were inconclusive and more such tests are needed. Additional tests testing with hot water for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 98/99 winter.

The primary objective of 97/98 testing was the performance evaluation of new and previously qualified Type IV fluids over the entire range of conditions encompassed by the holdover time tables. The effect of different variables on the fluid holdover time, in particular the effect of fluid viscosity, was examined and deemed to be significant. As a result, any future Type IV fluid holdover time testing will be conducted using samples representative of the manufacturers lowest recommended on-wing viscosity. Current methods for establishing holdover times in snow involve outdoor testing, which has been the source of industry concern for some time. It is recommended that a snowmaking device in development need to be evaluated for the future conduct of snow holdover time tests in controlled conditions. The study of fluid buffers was also continued in 97/98 and identified several industry concerns which will be addressed in further research. The adherence of contaminated fluid to aircraft wings was also evaluated in a series of simulated takeoff runs without aircraft rotation. Further research in these areas is needed.

2. PROGRAM OBJECTIVE (MCR 16)

Take an active and participatory role to advance aircraft ground de-icing/anti-icing technology. Develop international standards, guidance material for remote and runway-end de-icing facilities, and more reliable methods of predicting de-icing/anti- icing holdover times.

3. PROGRAM SUB-OBJECTIVES

3.1. Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions.

3.2. Substantiate the guideline values in the existing holdover time (HOT) tables for fluids that have been qualified as acceptable on the basis of their impact on aircraft take-off performance.

3.3. Perform tests to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces.

3.4. Support development of improved approaches to protecting aircraft surfaces from winter precipitation.

4. PROJECT OBJECTIVES

4.1. Develop holdover time data for all newly qualified de/anti-icing fluids.
4.2. Develop holdover time data for Type IV fluids using lowest qualifying viscosity samples.
4.3. Develop supplementary data for a reduced buffer 'de-icing only' Table.
4.4. Determine whether recycled, recovered fluid can be used as a 'De-icing only' fluid.
4.5. Determine whether the extreme precipitation rates used for laboratory testing of de/anti-icing fluids are in fact encountered in practice.
4.6. Obtain equipment for laboratory production of artificial snow which most closely reproduces natural snow.
4.7. Assess the limiting conditions of wind, precipitation and temperature under which water can be used as the first step of a two-step de-icing procedure.
4.8. Determine the patterns of frost formation and of fluid failure initiation and progression on the wings of high-wing turbo-prop and jet commuter aircraft.
4.9. Assess the practicality of using vehicle-mounted remote contamination detection sensors for pre-flight (end-of-runway) inspection.
4.10. Provide base data on the capabilities of remote sensors.
4.11. Provide pilots with reference data for the identification of fluid failure. Quantify pilot capabilities to identify fluid failure
4.12. Provide support services for the conduct of tests to determine under what conditions contaminated fluid adheres to aircraft lifting surfaces.
4.13. Assess whether pre-warming fuel at time of re-fuelling will help to eliminate the 'cold soaked' wing problem.
4.14. Develop a low-cost test wing which can be used in the laboratory in lieu of field testing full scale aircraft.
4.15. Establish the safe limits for de-icing truck operation when de-icing aircraft with the engines running.
4.16. Provide general support services.
4.17. Disseminate test findings

5. DETAILED STATEMENT OF WORK

5.1. General

5.1.1. Planning and Control

Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures (as specified in Section 9,"Project Control") within three weeks of effective commencement date, confirming task priorities, suggesting hardware and software suppliers, broadly identifying data needs and defining the roles of subcontractors, and submit to TDC for review and approval.

5.1.2. Safety and Security

Particular consideration will be given to safety in and around aircraft on the airport and deicing sites In the event of conflict between access for data gathering to obtain required test results and safety considerations, safety shall always govern.

5.2. Holdover Time Testing and Evaluation of De/Anti-icing Fluids

5.2.1. Newly Certified Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and to develop individual Holdover Time Tables based on samples of newly certified or re-certified fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate tests for one new fluid. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests will be performed in the laboratory. All testing shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

5.2.2. Low Viscosity Type IV Anti-icing Fluids

Fluid holdover time testing of Type IV fluids will be conducted using procedures established during past test seasons but using fluid with the lowest operational use viscosity.

5.2.2.1. Flat Plate Tests for New Type IV Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and develop individual Holdover Time Tables based on samples of new Type IV fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate for four new fluids using samples with one viscosity. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests shall be performed in the laboratory using methodology applied in past years.

5.2.2.2.Effect on Holdover Time of Viscosity

Conduct tests aimed at determining the effect of fluid viscosity on holdover time. Tests shall be conducted in light freezing rain and freezing drizzle conditions at various temperatures in the National Research council (NRC) Climatic Environment facility (CEF) using low and high viscosity samples representing production limits of three anti-icing fluids: a propylene, an ethylene and the Fluid X (which will become the benchmark for laboratory based HOT testing).

Anticipate a total of approximately 100 tests to be conducted under ZR- and ZD at -3 and -10 Celsius at low and high rates.

5.2.3. Recycled Fluids as Type I Fluids

5.2.3.1.Holdover Times

A complete set of holdover time tests shall be conducted using two fluid test samples of recovered glycol based freezing point depressant fluid which have been recycled and exhibit nominal conformance to Type I de-icing fluid performance characteristics. The objective of this series of tests is to establish a sound base of data sufficient to establish valid holdover time tables for these fluids.

5.2.3.2.Compatibility with Type IV Fluids

Fluid compatibilty trials shall be conducted using various combinations of the recycled fluids and commercial Type IV fluids. Determine how the Inland fluids perform when used in conjunction with a Type IV fluid overspray.

5.3. Supplementary Data for Deicing Only Table

Evaluate the test conditions used in establishing the deicing only table by undertaking the following test series at sub zero temperatures but with no precipitation.

5.3.1. Establish Quantity of Fluid for Field Tests.

Conduct a series of comparative laboratory tests with 0.5, 0.25 and 0.1 litre per plate. Consider the case of spraying for frost with a fan shape to cover a wide area with a small amount of fluid compared with a stream as used to remove snow or ice. Examine typical fluid quantities representing frost removal spray. Conduct some tests on aircraft piggybacking on other testing if feasible.

5.3.2. Establish Temperature of Fluid for Field Tests

Laboratory tests will be performed with fluids initial temperatures at the spray nozzle of 60°C, 50°C, and 40°C initial temperature.

Field tests on aircraft will be designed to measure the loss of fluid temperature and to measure fluid evaporation and enrichment during the air transport phase between spray nozzle and wing surfaces, for various distances and shapes of spray pattern (3 distances; 2 spray patterns).

5.3.2.1.
Examine the effect on the final freeze point of sprayed fluids on the wing, resulting from variations in the temperature of the fluid (60°C, 50°C, and 40°C).
5.3.2.2.
Examine the effect on wing heat and fluid evaporation of removing contaminant from the wing surface. Various degrees of ice depth shall be deposited using a hand-held rainmaker, including a very light coating to simulate frost. The amount of fluid sprayed shall be controlled by the operator, spraying until a clean surface results.

5.3.3. Perform tests at current buffer limit as baseline.
Perform a series of comparative tests using buffers at 3°C and 10°C to compare to the new data and the data collected last season with buffers at 0°C .

5.3.4. Simulate High Wind Conditions
Tests shall be performed using NRC fans producing winds up to 30 kph for comparison with the earlier series of tests with speeds up to 20 kph

5.3.5. High Relative Humidity
Perform a series of plate tests at 90% RH to compare results to those already gathered. Review the condition with weather services to determine typical RH values during deicing only conditions.

5.3.6. Cold Soaked Wings
Perform a series of tests on cold soak boxes to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT. These tests can be run in conjunction with high humidity tests when deposition of frost on cold soaked surfaces would normally be expected.

5.3.7. Effect of Snow Removal on Fluid Heat Input
Perform tests to establish whether removal of snow results in extesive amounts of heat being carried away and insufficient heat being transferred to the wing during deicing.
Expose flat plates to snowfall (either natural or as simulated by approved equipment) and protect snow catches of various thicknesses. Tests shall be run in an area protected from further snowfall. Fluid shall be applied with a hand sprayer, until the plate is cleaned, measuring the amount of fluid applied. The final fluid concentration on the plate shall be measured. The heat lost in fluid run off shall be measured. Parallel tests will be conducted on bare surfaces.

A carefully calculated heat balance shall be determined for each experiment based on the temperatures of the applied fluid, the plate and the collected run-off material.

5.3.8. Effect of Composite Surfaces on Evaporation

Evaluate the effects of the use of composite materials in wings on the heat transfer from deicing fluid to the wing. Conduct a series of laboratory comparative tests on a several samples of composite surfaces.
Identify an appropriate aircraft having a wing surface composed of new technology composite material as well as aluminium, determining the thermal pathways connecting the composite surfaces to the main wing structure.
Conduct field tests on a sample aircraft.

5.3.9. Unpowered Flight Control Surfaces

Field trials will be conducted on DC9 aircraft to assess the impact of fluids of various buffers on the freedom of operation of the unpowered elevator control tabs to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT

5.3.10. Field Tests on Aircraft

Three overnight test sessions shall be planned for these tests. Tests shall be conducted on aircraft types including the McDonnell Douglas DC-9 and Canadair RJ, with a minimum of one night for each type. Testing on a third aircraft type would be useful to improve confidence and to confirm the universality of the results. Use an ice detector sensor system to provide a separate source of data.

5.3.11. Laboratory Tests

The number of proposed tests shall be controlled by limiting tests to the minimum number of ambient conditions that will support conclusions on the significance of the issues raised while maintaining a good level of confidence. As a minimum, this encompasses about 230 plate tests and would require about 8 days at the NRC CEF Facility or other suitable facility.

5.4. Flow of Contaminated Fluids from Wings during Takeoff

5.4.1. Requirement

Evaluate anti-icing fluids for their influence on adherence, in particular, propylene based Type IV fluids which were observed during fluid failure
A test plan shall be developed jointly with NRC.
Two days of testing at Mirabel Airport shall be planned.
Use an ice contamination sensor to assist in documenting contamination levels to provide valuable assistance in data gathering. A contingency allowance to fund sensor company participation shall be included.

Data collected during these trials shall include:

- type of fluid applied;
- record of contamination level prior to take off runs,;record of level of contamination following takeoff runs;
- observations, photography and video taping, and ice sensor records; and
- specifics on aircraft takeoff runs obtained from NRC personnel.

5.4.2. Conduct of Trials and Assembly of Results

Coordinate all test activities, initiating tests in conjunction with NRC test pilots based on forecast weather. Analyse results and document all findings in a final technical report and in presentation format.

5.5. Aircraft Full-Scale Tests

5.5.1. Purpose of Tests

Conduct full-scale aircraft tests:

- To generate data which can be used to assist pilots with visual identification of fluid failure;
- To generate data to be used to assess a pilot's field of view during adverse conditions of winter precipitation for selected aircraft; (See item 5.11)
- To compare the performance of de/anti-icing fluids on aircraft surfaces with the performance of de/anti-icing fluids on flat plates;
- To examine the pattern of failure using Type IV fluid brands not tested in the past; and
- To further investigate progression of failure on the two wings in crosswind conditions.

5.5.2. Planning and Coordination

Planning and preparation for tests including provision of facilities, personnel selection and training, and test scheduling shall be the same as provided to TDC in previous years

5.5.3. Testing

All tests and dry runs shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.
Test planning will be based on the following aircraft and facilities:

Aircraft	Airline	Test Locn.	Deicing Pad	Deicing Crew
Canadair RJ	Air Canada	Dorval	Central	Aéromag 2000
ATR42	Inter Canadian	Dorval	Central	Aéromag 2000

5.5.4. Test Measurements

Make the following measurements during the conduct of each test:

- Contaminated thickness histories at selected points on the wings. The selection of test points shall be made in cooperation with the Transportation Development Centre,
- Contamination histories at selected points on wings (selected in cooperation with the Transportation Development Centre),
- Location and time of first failure of fluids on the wings,
- Pattern and history of fluid failure progression,
- Time to failure of one third of the wing surface
- Concurrent measurement of time to failure of fluids on flat plates. The plates will be mounted on standard frames and on aircraft wings at agreed locations,
- Wing temperature distributions,
- Amount of fluid applied in each test run and fluid temperature,
- Meteorological conditions, and
- For crosswind tasks, effects of rate of accumulation on each wing.

In the event that there is no precipitation during full-scale tests, the opportunity shall be taken to make measurements of fluid thickness distributions on the wings. These measurements shall be repeated for a number of fluid applications to assess the uniformity of fluid application.

5.5.5. Pilot Observations

Contact airlines and arrange for pilots to be present during the tests to observe fluid failure and failure progression, and to record pilot observations from the cockpit and the cabin for later correlation with aircraft external observations.

5.5.6. Remote Sensor Records

Record the progression of fluid failure on the wing using RVSI and/or Cox remote contamination detection sensors if these sensors are made available.

5.6. Snowmaking Methods and Laboratory Testing for Holdover Times

5.6.1. Evaluation of Winter Weather Data

5.6.1.1. Snow Rates

Collect and evaluate snow weather data (precipitation rate/temperature data) during the winter to ascertain the suitability of the data ranges used to date for evaluation of holdover time limits.

Obtain current data from Environment Canada for three sites in Quebec: Rouyn, Pointe-au-père (Mont-Joli), and Ancienne Lorette (Quebec City), in addition to Dorval (Montreal).

5.6.1.2. Fog Deposition Rates

Devise a procedure and conduct fog deposition measurements outdoors on at least two occasions to determine the range of fog deposition rates which occur in natural conditions.

5.6.1.3. Frost Deposition Rates

Frost deposition rates shall be collected at various temperatures in natural conditions in order to determine a deposition range for this condition. Consideration shall be given to collecting deposition rates in cold temperatures (for example in Thompson, Manitoba). A total of five sessions shall be planned.

5.6.2. Snowmaking Methods

Acquire a version of the new snow generation system recently developed by the National Centre for Atmospheric Research (NCAR).

Evaluate the NCAR system for the future conduct of holdover time testing in simulated snow conditions. Tests shall be conducted in a small climatic chamber at Concordia University, PMG Technologies, or at NRC. Tests shall also be conducted with one Type IV fluid over a range of temperature and snowfall rates to compare the SAE holdover times for this fluid in natural and simulated conditions.

A further series of tests shall be performed with the system in order to assess the holdover time performance of the reference fluid (as described in the proposed SAE test procedures).

A total of 8 days of climatic chamber rental shall be planned for the conduct of the proposed tests.

5.7. Documentation of Appearance of Fluid Failure for Pilots

Current failure documentation deals largely with freezing drizzle and freezing rain conditions

5.7.1. Documentation of Failures

Finalise documentation of failure through limited further research as follows:

5.7.1.1.

provide similar documentation for fluids exposed to snow conditions, taking advantage of the availability of a snow making device for laboratory use;

5.7.1.2.

provide documentation for a propylene based Type IV fluid at typical delivered viscosity, for precipitation conditions tested previously, to determine characteristics at its operational limits and the nature and mechanisms of failure. Conduct selected comparison tests with a second fluid to test commonality of responses. Data from this activity will be cross-analysed with data from proposed research to examine the flow of similar fluids at different levels of contamination from aircraft wings during a simulated takeoff; and

5.7.1.3.

examine and document the appearance and nature of failure of propylene base fluids at cold temperatures (-10 C).

5.7.1.4.
Conduct tests at the National Research Council Climatic Environmental Facility based on last years' procedures, with enhancements as necessary and available. Snow documentation may be conducted in a different laboratory facility. Documentation under outdoor snow conditions will be conducted for comparison purposes to laboratory conditions.

5.7.2. Conduct of trials/assembly of results
Coordinate all test activities, scheduling tests with NRC CEF in conjunction with other test activities. Analyse results and document all findings, recommendations and conclusions in a final technical report and in presentation format. Provide timely updates of schedule revisions to TDC.

5.7.3. Pilot Observations
Contact airlines and arrange for pilots to be present during tests to observe fluid failure and failure progression. Record pilot observations for later correlation with aircraft external observations.

5.8. Feasibility of Performing Wing Inspections at End-of-runway

5.8.1. Requirement
Examine the feasibility of scanning aircraft wings with ice contamination sensors just prior to aircraft entering the departure runway using Dorval airport as an example scenario.
Explore ways of positioning sensors at agreed locations on an airport.
Composition and conduct of tests shall be adapted as information is gained on the practicality of this activity.

5.8.2. Planning
A Project Plan shall be prepared which will include:

a) activities to determine the parameters, operational issues and constraints related to the proposed process, and
b) a test plan for operational trials to examine the capabilities of the contamination sensors to determine the feasibility of their operational use.

The test plan for operational trials (three sessions) shall include:

- establishing test locations with airport authorities,
- establishing operational procedures with airport authorities,
- arranging equipment for scanning; vehicle, sensor installation and radios,
- collecting and coordinating information from the deicing activity at the deicing centre,
- test procedures with detailed responsibilities for all participants,
- control of the confidential data gathered on wing condition, and

- notification to all concerned in the project, including aircraft operators, that scanning activities will take place.

5.8.3. Coordination

Coordination all activites with authorities from Aéroports de Montréal and arrange support from Cox and/or RVSI

5.8.4. Field Trials

Conduct trials to further evaluate the feasibility of integrating such a process within current airport operations management, as well as to gather information on wing condition, just prior to takeoff, during deicing operations. These trials shall be based on the use of mobile equipment currently available. A "truthing" test pannel shall be present at each trial to demonstrate the validity of the wing readings on an ongoing basis

The trials shall be designed to address issues such as:

- equipment positioning versus current runway clearance limitations,
- time delay between inspection and start of take-off
- system capabilityto meet its design objectives in severe weather
- suitability of mobile equipment or fixed facility.
- need for rapid extension and retraction of sensor booms,
- airport support needed, e.g. snow clearance, provision of operating locations,
- accommodating scanner limitations for distance, light, angle of incidence.
- communications needed to support scanning operation,
- recording data from the sensors, and
- communicating results of the scanning to pilots and regulatory authorities.

5.8.5. Test Personnel and Participation

Initiate all tests based on suitable weather conditions. The individual test occasions shall be coordinated with Aéroports de Montréal and Aéromag 2000. Coordinate the provision of a suitable vehicle and the installation of an ice detection sensor. Monitor the test activity, ensuring the collection and protection of all scanning data, as well as the collection of data related to weather conditions and previous aircraft deicing activities. Ensure that the instrument providers deliver data and an objective measure of wing contamination based on scanner information in a timely and reproducible manner.

5.8.6. Study Results

Results from the feasibility study shall be presented in technical report format which shall include comments pertinent to long term implementation.

Results from the scanner tests shall be provided in technical report format and shall include analysis of wing contamination data cross-referred to the deicing history of individual aircraft scanned.

5.9. Ice Detection Sensor Certification Testing

5.9.1. Minimum Ice Thickness Detectable in Tactile Tests

Prepare procedures and conduct tests to establish human limits in identifying ice through tactile senses. These tests shall use the NRC or equivalent test facilities acceptable to TDC and a test setup equivalent to that planned for sensor certification. Several ice thicknesses and textures shall be tested to establish tactile sensing limiting thickness for smooth ice and for roughened ice.

The experiment shall involve sufficient participants and test conditions such as to provide reliable results usable in approving sensors to replace human tactile testing.

TDC shall assist in the experimental design

Tests shall be conducted with both contractor personnel and a selection of pilots as subjects.

A professional human factors scientist shall be used to establish testing parameters such as:

- what proportion of plates should be bare
- whether subjects should be blindfolded to eliminate visual cues.
- whether the same plate should be judged more than once
- how to ensure that subjects do not compare plates
- what should be the minimum time between plate touching

Results of the tests shall be analysed statistically to establish confidence limits for the findings

5.9.2. Field Tests for Sensor Distance and View Angle Limits

Develop a detailed test plan with a matrix of all test parameters, required coordination of equipment detailing the responsibilities of all participants.

Collect test data, including photo and video records of all tests.

The areas of ice contamination used for sensor evaluation shall be quantified by size, location and thickness. Angles of incidence, sensor heights and distances shall be verified independently. In concert with the sesor manufacturer, data from sensor readings and observer data shall be collated and analysed to reach conclusions on sensor limitations for distance and angle of incidence in various weather conditions.

5.10. Planning a Wing Deicing Test Site

Develop a plan for implementing a deicing test site, centred on an aircraft wing and supported by current fluid and rainmaking sprayers.

The plan shall include the acquisition of a surplus complete wing, from either a scrapped or an accidented moderate sized aircraft or an outboard section of a larger aircraft. The wing section should if possible include ailerons and leading edge slats
The design of the test site shall include a test area that could contain and recover sprayed fluids. Installation of the wing should entail a mounting designed to allow the wing to be rotated relative to current winds. The site must be secure yet allow ease of access and ability to install inexpensive solutions to control sprayed fluid.
Costs shall be estimated for the main elements of the development of a wing test bed site including:
wing purchase and delivery,
site lease and development, and
wing mount design and fabrication.

5.11. Evaluation of Hot (and Cold) Water Deicing

Investigate unheated and hot water deicing/defrosting, to determine under what meteorological conditions and temperatures these procedures are safe and practicable.
Unheated water deicing shall be evaluated at air temperatures above 1 degree C(34 degrees F).
Hot water deicing shall be evaluated at air temperatures below 1 degree C and include temperatures below –3 degrees C (27 degrees F).
These experiments shall establish how long it takes for the water to freeze on the surface under these conditions.
This is to be the first step of a two step procedure. From these data, a safe and practical lower limit shall be established considering the three-minute window required for second step anti-icing in the two-step deicing procedure.
Precipitation rates, as utilised in the generation of holdover time tables, shall be considered. Environmental chamber tests shall be correlated with outdoor aircraft tests. All laboratory test procedures and representative test results shall be recorded on videotape, including failure modes where applicable. The video shall depict a recommended full-scale aircraft hot water deicing procedure. A written report shall include the laboratory test results and a recommended aircraft unheated/hot water deicing procedure, including the limitations of precipitation, OAT and wind.

5.12. Evaluation of Warm Refuelling

Conduct a feasibility study of the suitability of refuelling with warm fuel to reduce susceptibility to "cold-soaked wing" icing, and to improve holdover times.
Coordinate activities to support testing the "warm fuel" concept using operational aircraft, including arranging;

- Participation of interested airlines, along with provision of aircraft for test purposes;
- Participation of local refueller;
- Arrangements with the equipment supplier (Polaris) to deliver the equipment to the selected airport along with the required technical support.

Testing will be conducted at Dorval on three occasions, one of which will include snow or freezing precipitation. Test aircraft selected should include a representation of both "wet" and "dry" wings if possible.
Wing surface temperatures of test wings will be monitored at several points over a period of time, to assess the influence thereon of warmed fuel. A reference case based on fuel boarded at the normal local temperature will be conducted.

5.13. Engine Air Velocity Distributions near Deicing Vehicles

Measure air velocity distributions in the vicinity of a de-icing truck when de-icing a large aircraft whose engines are running.
Tests shall be conducted during a period of no precipitation, either frost deicing or following snowfall, on two separate occasions at the Dorval International Airport deicing facility. Aircraft with engines mounted on the wing (e.g. B737) as well as rear engines mounted aircraft (e.g. DC-9 and RJ) will be sampled during live deicing operations, the precise type to be agreed by TDC. The tests shall be coordinated with Aéroport de Montréal and Aéromag 2000.
Wind velocity shall be measured from an Elephant-mu de-icing truck at locations recommended by TDC around the tail of the aircraft at different elevations and distances from the engines depending on the aircraft type, and the de-icing procedure followed by Aéromag 2000.
Photograph and video record the conduct of all tests.

5.14. Provision of Support Services

Provide support services to assist TDC with testing, the reduction of data and presentation of findings in the activites identified below which relate to the content of this work statement, but are not specifically included.

5.14.1.Re-Hydration

Conduct a series of exploratory trials on flat plates at the Dorval site or NRC to observe the behaviour of re-hydrated Type IV fluids and to help determine how re-hydration affects the flow- off characteristics of a Type IV fluid exposed to frost conditions.

5.14.2.Frost Tests on a Regional Jet

Conduct a series of tests to determine the roughness of frost deposition on the wings of a Regional Jet aircraft. Conduct tests on three overnight occasions.

5.14.3.Ice-Phobic Materials Evaluation

Conduct a series of tests on flat plates to determine the effects of ice-phobic materials on the film thickness and on holdover time of de/anti-icing fluids.

5.14.4.Evaluation of Infra-Red Thermometers

Evaluate use of infra-red technology as a method of determining accurate skin and fluid temperatures during operational conditions. Conduct tests in conjunction with full-scale and holdover time testing.

5.14.5.Frost Self-Elimination

Examine the self-elimination of frost on several test surfaces under variable weather conditions. Conduct test in conjunction with frost deposition trials on flat plates.

5.14.6.Environmental Impact Assessment

Assess the environmental issues related to the use of glycol-based products for aircraft de-icing purposes. Examine the waste fluid collection and disposal procedures for several deicing facilities in relation to current and future environmental legislation.

5.14.7.An Approach to Establish Wing Contamination

Document an approach to determining operational limits for levels of contamination on aircraft wings. This approach will include consideration of the location of contamination on the wings and the area contaminated. The levels of contamination on aircraft wings prior to takeoff as determined during the scanning trials prior to takeoff will be factored in.

The approach will discuss how the limits (when defined) could be used in software routines to enable sensor systems to provide Go/No-Go indications to the aircraft pilot and regulatory authorities.

5.14.8. Accident/incident Database Analysis

Provision of database manipulation and support aimed at establishing problem areas and their significance.

5.14.9.Other activities

Other activities, such as the evaluation of forced air technology, the evaluation of alternate (zero glycol) deicing methods, and the evaluation of frost removal equipment at gates, or others may emerge as issues during the course of the winter season.

APPENDIX B

EXPERIMENTAL PROGRAM

TRIALS TO ASSESS THE PERFORMANCE OF THE NCAR SNOW GENERATION SYSTEM

CM1514.001

EXPERIMENTAL PROGRAM

TRIALS TO ASSESS THE PERFORMANCE OF THE NCAR SNOW GENERATION SYSTEM

Winter 1998/99

APS AVIATION INC.

February 18, 1999
Version 1.1

EXPERIMENTAL PROGRAM
TRIALS TO ASSESS THE PERFORMANCE OF THE NCAR SNOW GENERATION SYSTEM

Winter 1998/99

This set of tests will produce the data required for evaluating the snow precipitation conditions produced by the NCAR snow generation system.

1 OBJECTIVES

The purpose of these tests is to evaluate the NCAR system for the future conduct of holdover time testing and documentation of fluid failure appearances in simulated snow conditions.

The tests required to create holdover time tables for snow conditions will be performed for a reference fluid and two known fluids.

The documentation of fluid failure appearance tests will be preformed for a reference fluid and three known fluids.

Snow types will be observed during the tests.

2 TEST REQUIREMENTS

Trials will be conducted at PMG Technologies or at NRC in Ottawa.

All Type IV fluids must be tested at outside air temperature. If the cold chamber is not maintained at low temperatures over night, the fluids must be refrigerated to ensure temperature is according to requirements.

Type I fluids must be at room temperature until the test is performed. They must not be stored in the cold chamber.

Temperatures of -3°C, -14°C, -25°C and 7°C above fluid freezing point are required for the holdover time tests.

Temperatures of -3°C and -10°C are required for the documentation of fluid failure appearance tests.

Attachment I presents a test matrix for these tests.

3 EQUIPMENT

Attachment II presents a list of required equipment for the holdover time tests.

The list of equipment required for the documentation of fluid failure appearance tests is included in the *Experimental Program Procedure for the Documentation of the Appearance of Failed Fluids for Indoor Tests*. The C/FIMS sensor should be used if available, but the C/FIMS computer will not be required for these tests.

4 PERSONNEL

The personnel requirements for the holdover time tests are as follows:

- One person to pour the fluids and to call the failure on the plate.
- One person part-time to assist in preparing the snow generation system and to verify it's correct operation.

The personnel requirements for the documentation of fluid failure appearance tests are as indicated in the *Experimental Program Procedure for the Documentation of the Appearance of Failed Fluids for Outdoor Tests*, with the exception that the Meteo Tester is not required since the rates are collected by the NCAR system.

5 SUMMARY OF PROCEDURES

The procedures for the holdover time tests are as indicated in the *Experimental Program For Dorval Natural Precipitation Flat Plate Testing* with the exception that the plate rate pans are not required since the rates are collected by the NCAR system.

The procedures for the documentation of fluid failure appearance tests are as indicated in the *Experimental Program Procedure for the Documentation of the Appearance of Failed Fluids for Indoor Tests*, with the exception that the plate rate pans are not required since the rates are collected by the NCAR system. The RVSI sensor will not be used for the snow making tests.

6 DATA FORM

The holdover time tests will only require the end condition data form.

The documentation of fluid failure appearance tests require the completion of the data forms included in the *Experimental Program Procedure for the Documentation of the Appearance of Failed Fluids for Indoor Tests*. The Meteo/Plate pan data form is not required since the rates are not collected manually.

ATTACHMENT I
Test Matrix

	Run #	Fluid Type	Dilution	OAT (°C)	Precipitation Rate (g/dm²/hr)	Estimated Duration (min)	Priority
Holdover Time Tests	1	X	100/0	-3	10	75	1
	2	X	100/0	-3	10	75	1
	3	X	100/0	-3	25	75	1
	4	X	100/0	-3	25	75	1
	5	X	100/0	-14	10	55	1
	6	X	100/0	-14	10	55	1
	7	X	100/0	-14	25	55	1
	8	X	100/0	-14	25	55	1
	9	X	100/0	-25	10	45	1
	10	X	100/0	-25	10	45	1
	11	X	100/0	-25	25	45	1
	12	X	100/0	-25	25	45	1
	13	X	100/0	Fz +7	10	40	1
	14	X	100/0	Fz +7	10	40	1
	15	X	100/0	Fz +7	25	40	1
	16	X	100/0	Fz +7	25	40	1
	17	UL +	100/0	-3	10	75	1
	18	UL +	100/0	-3	10	75	1
	19	UL +	100/0	-3	25	75	1
	20	UL +	100/0	-3	25	75	1
	21	UL +	100/0	-14	10	55	1
	22	UL +	100/0	-14	10	55	1
	23	UL +	100/0	-14	25	55	1
	24	UL +	100/0	-14	25	55	1
	25	UL +	100/0	-25	10	45	1
	26	UL +	100/0	-25	10	45	1
	27	UL +	100/0	-25	25	45	1
	28	UL +	100/0	-25	25	45	11
	29	UL +	100/0	Fz +7	10	40	1
	30	UL +	100/0	Fz +7	10	40	1
	31	UL +	100/0	Fz +7	25	40	1
	32	UL +	100/0	Fz +7	25	40	1
	33	Prop	100/0	-3	10	100	2
	34	Prop	100/0	-3	10	100	3
	35	Prop	100/0	-3	25	100	2
	36	Prop	100/0	-3	25	100	3
	37	Prop	75/25	-3	10	65	2
	38	Prop	75/25	-3	10	65	3
	39	Prop	75/25	-3	25	65	2
	40	Prop	75/25	-3	25	65	3
	41	Prop	50/50	-3	10	15	2
	42	Prop	50/50	-3	10	15	3
	43	Prop	50/50	-3	25	15	2
	44	Prop	50/50	-3	25	15	3
	45	Prop	100/0	-14	10	80	2
	46	Prop	100/0	-14	10	80	3
	47	Prop	100/0	-14	25	80	2
	48	Prop	100/0	-14	25	80	3
	49	Prop	75/25	-14	10	65	2
	50	Prop	75/25	-14	10	65	3
	51	Prop	75/25	-14	25	65	2
	52	Prop	75/25	-14	25	65	3
	53	Prop	100/0	-25	10	70	2
	54	Prop	100/0	-25	10	70	3
	55	Prop	100/0	-25	25	70	2
	56	Prop	100/0	-25	25	70	3
	57	Prop	100/0	Fz +7	10	65	2

Run #	Fluid Type	Dilution	OAT (°C)	Precipitation Rate (g/dm²/hr)	Estimated Duration (min)	Priority
58	Prop	100/0	Fz +7	10	65	3
59	Prop	100/0	Fz +7	25	65	2
60	Prop	100/0	Fz +7	25	65	3

Documentation Tests

61	X	100/0	-3	10	100	
62	X	100/0	-3	10	100	
63	X	100/0	-3	25	100	
64	X	100/0	-3	25	100	
65	X	100/0	-10	25	100	
66	X	100/0	-10	25	100	
67	XL 54	100/0	-3	25	30	
68	XL 54	100/0	-3	25	30	
69	UL +	100/0	-3	10	85	
70	UL +	100/0	-3	10	85	
71	UL +	100/0	-3	25	85	
72	UL +	100/0	-3	25	85	
73	UL +	100/0	-10	25	65	
74	UL +	100/0	-10	25	65	
75	Prop	100/0	-3	10	120	
76	Prop	100/0	-3	10	120	
77	Prop	100/0	-3	25	120	
78	Prop	100/0	-3	25	120	
79	Prop	100/0	-10	25	100	
80	Prop	100/0	-10	25	100	

Estimated	Totals
Minutes	5370
Hours	89.5
Days	11.1875

ATTACHMENT II
TEST EQUIPEMENT CHECKLIST

- Snow making machine and related equipment;
- Aluminum plate;
- Fluid thickness gauge;
- Squeegee/scraper;
- Extension cord;
- Paper towels;
- Rags;
- Flood lights;
- Stopwatch;
- Wet vacuum;
- Brixometer;
- Data forms;
- Mast light;
- Video camera;
- Photo camera;
- RH Meter;
- Extension Cords.

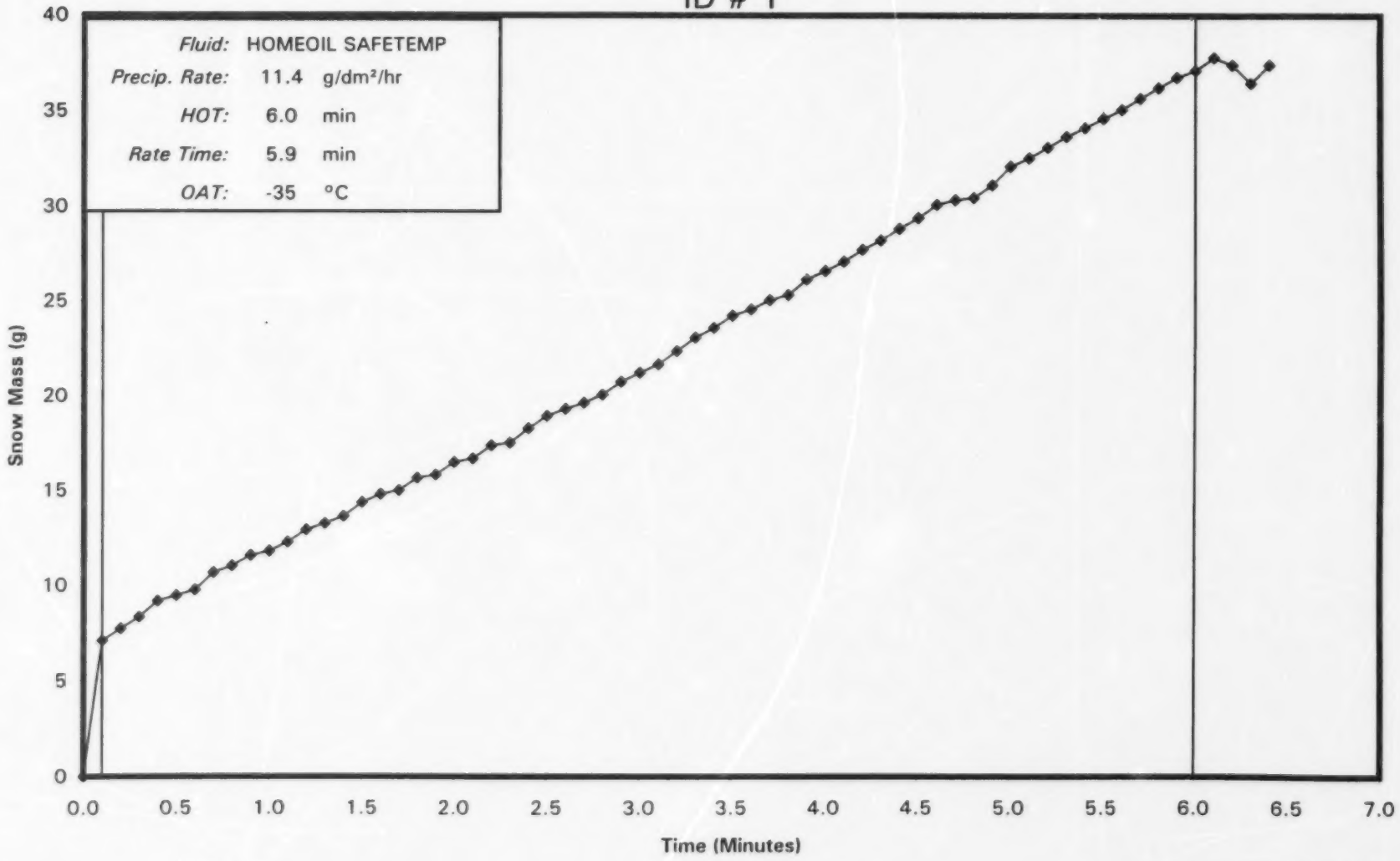
APPENDIX C

ACCUMULATION OF PRECIPITATION DURING INDOOR TYPE I TESTS

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 1

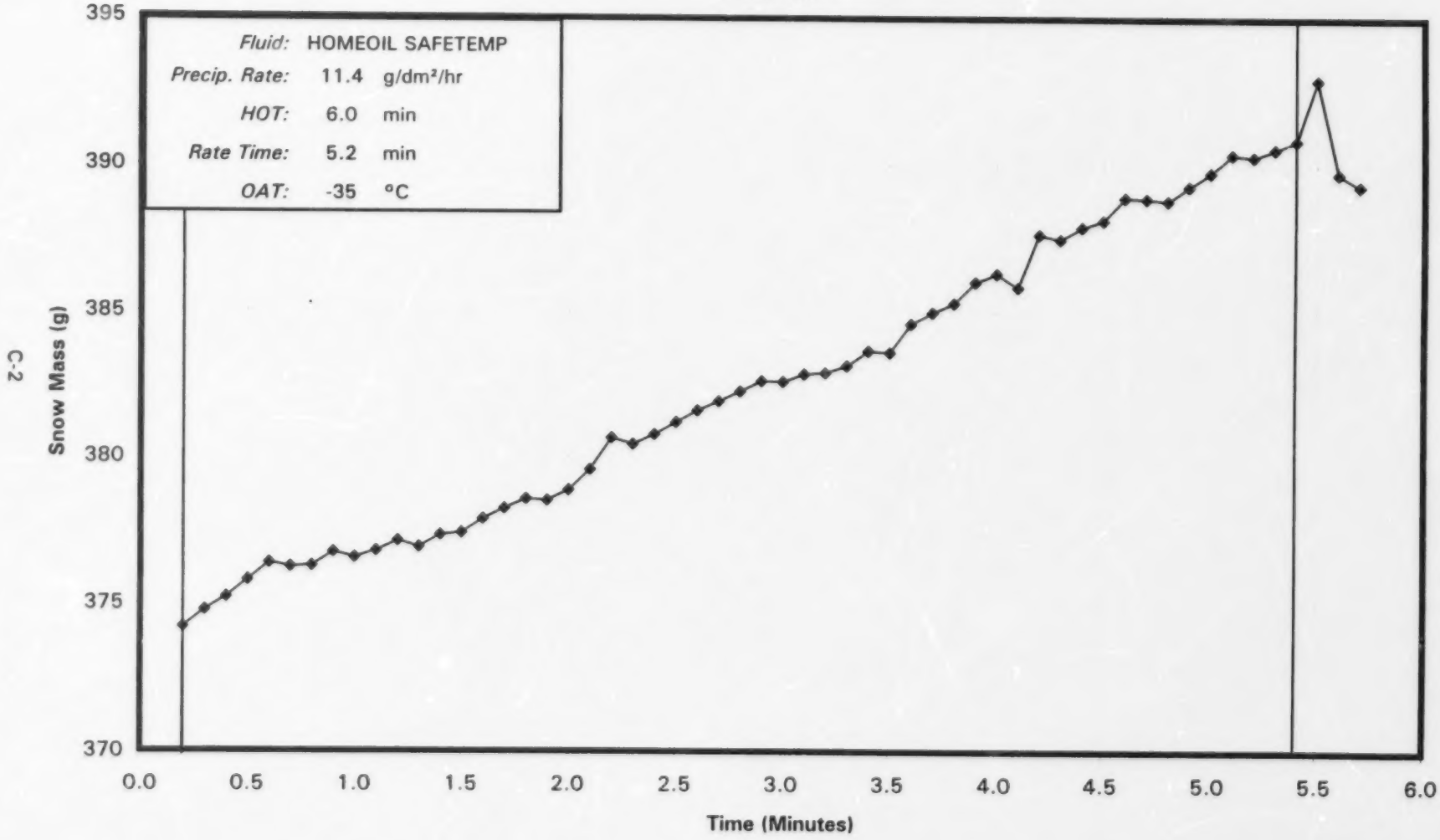


cm1514/analysis/ncar_jly/id_01
9/24/99, 2:43 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 2



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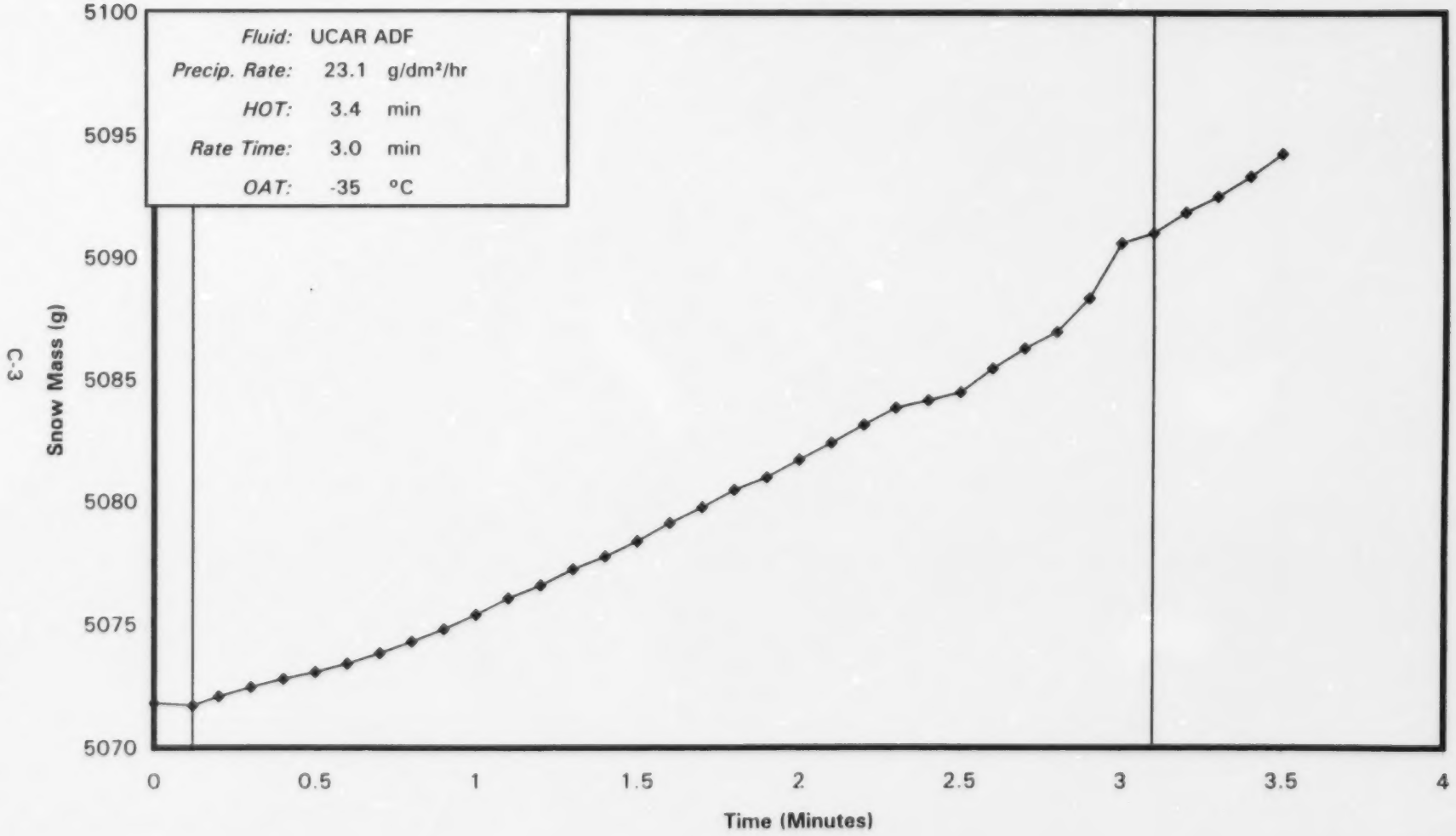
9/24/99, 2:43 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 3

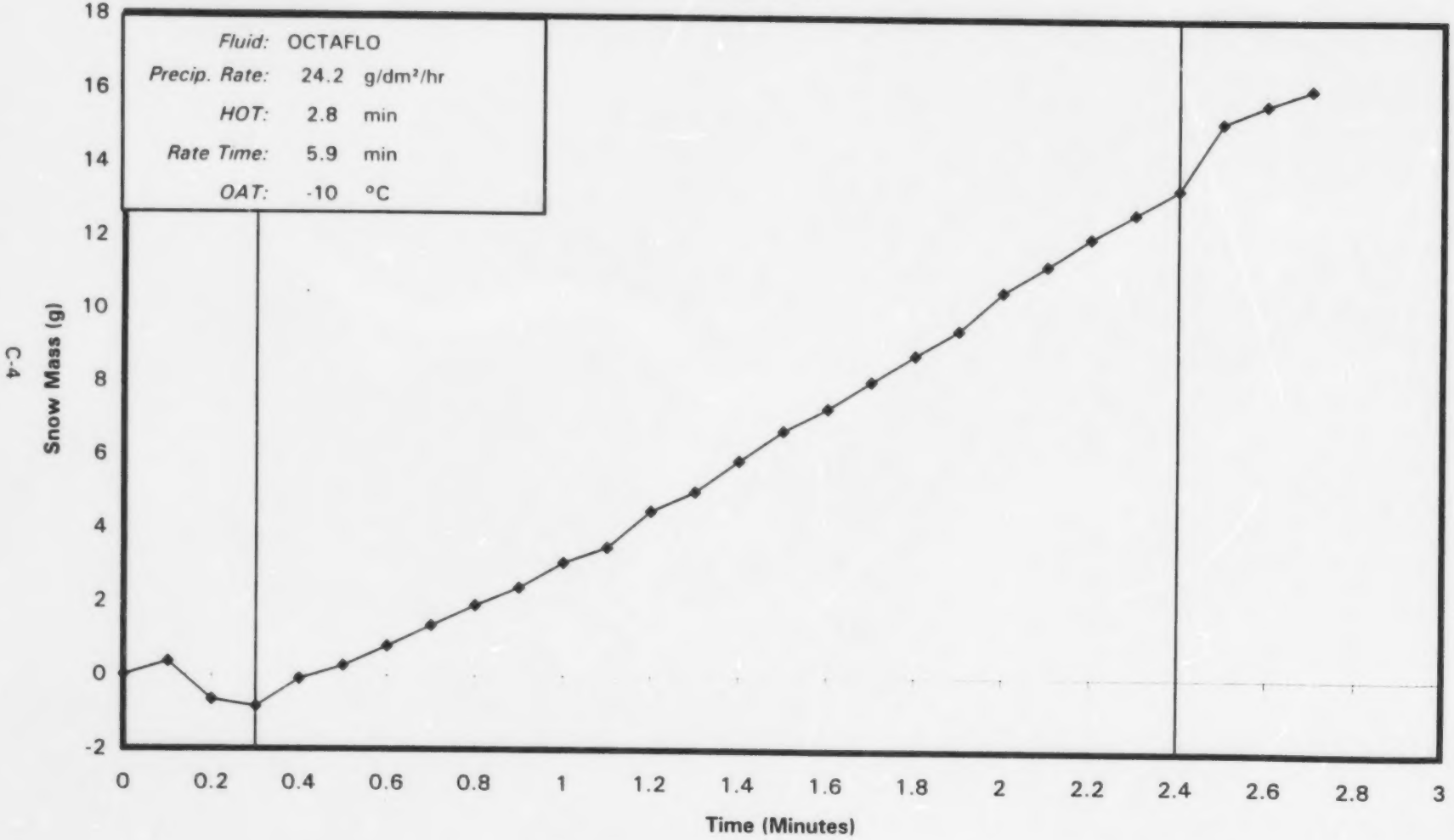


Id_03
9/24/99, 2:44 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 4



Id_04
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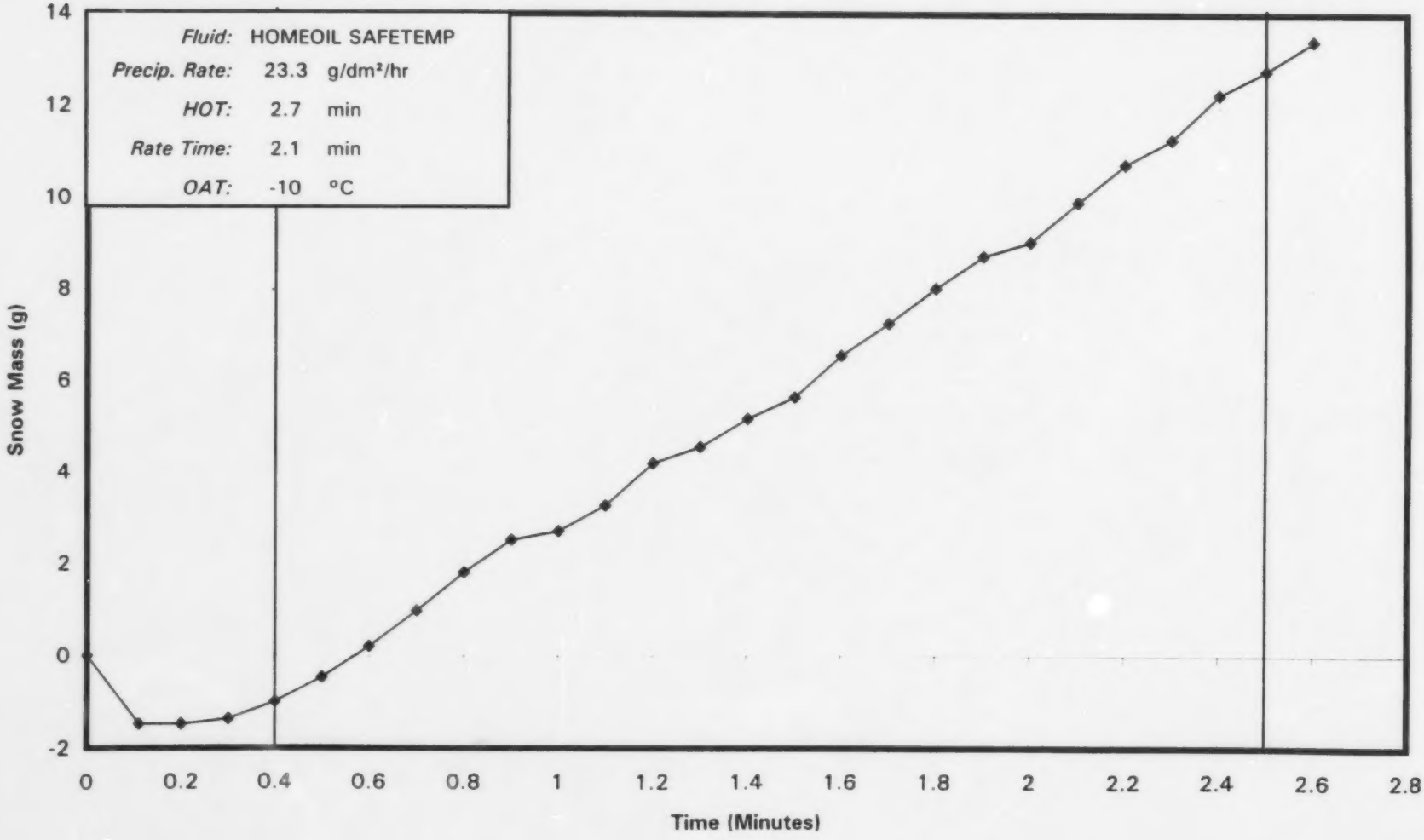
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 5



Id_05
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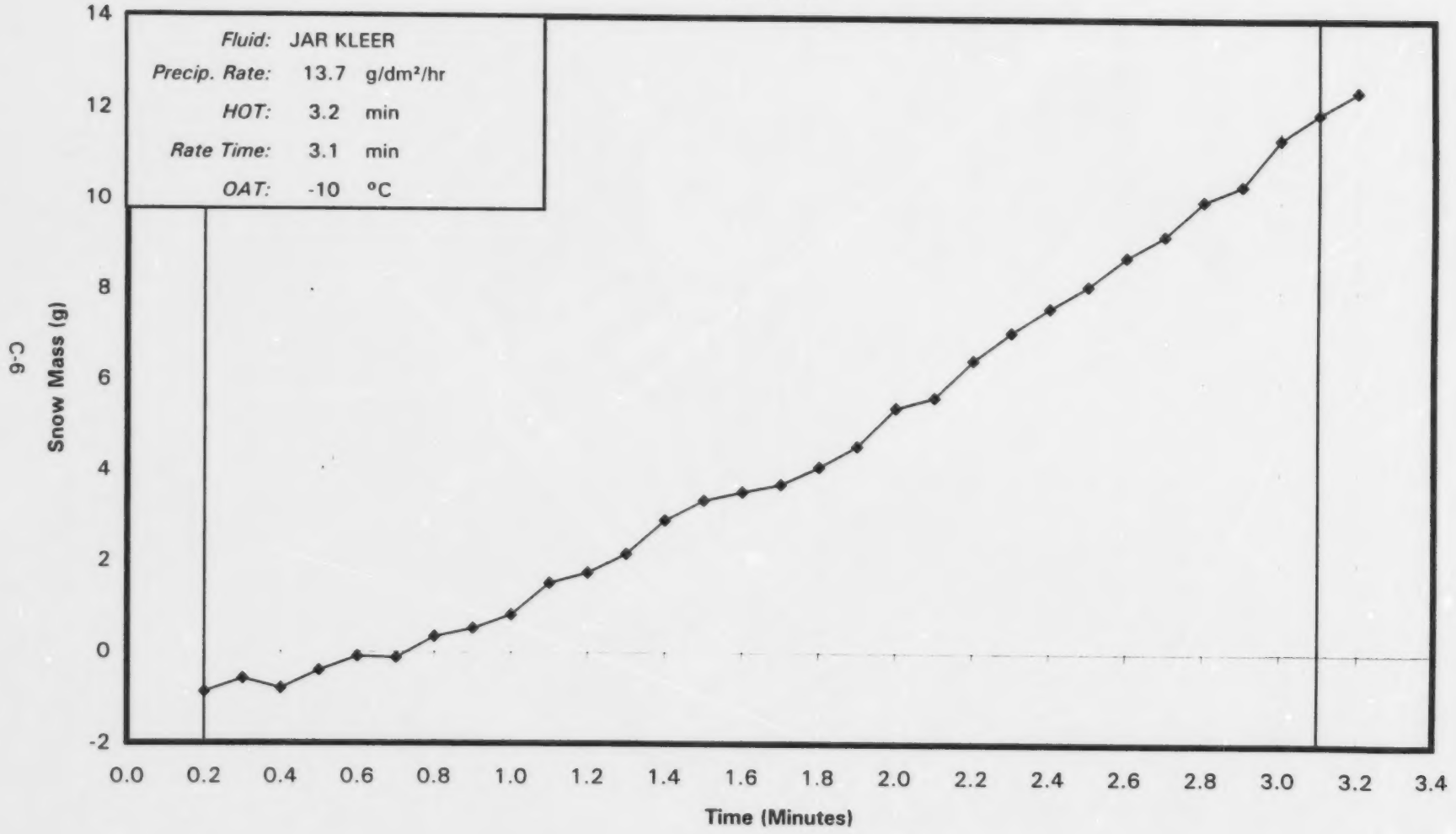
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 6

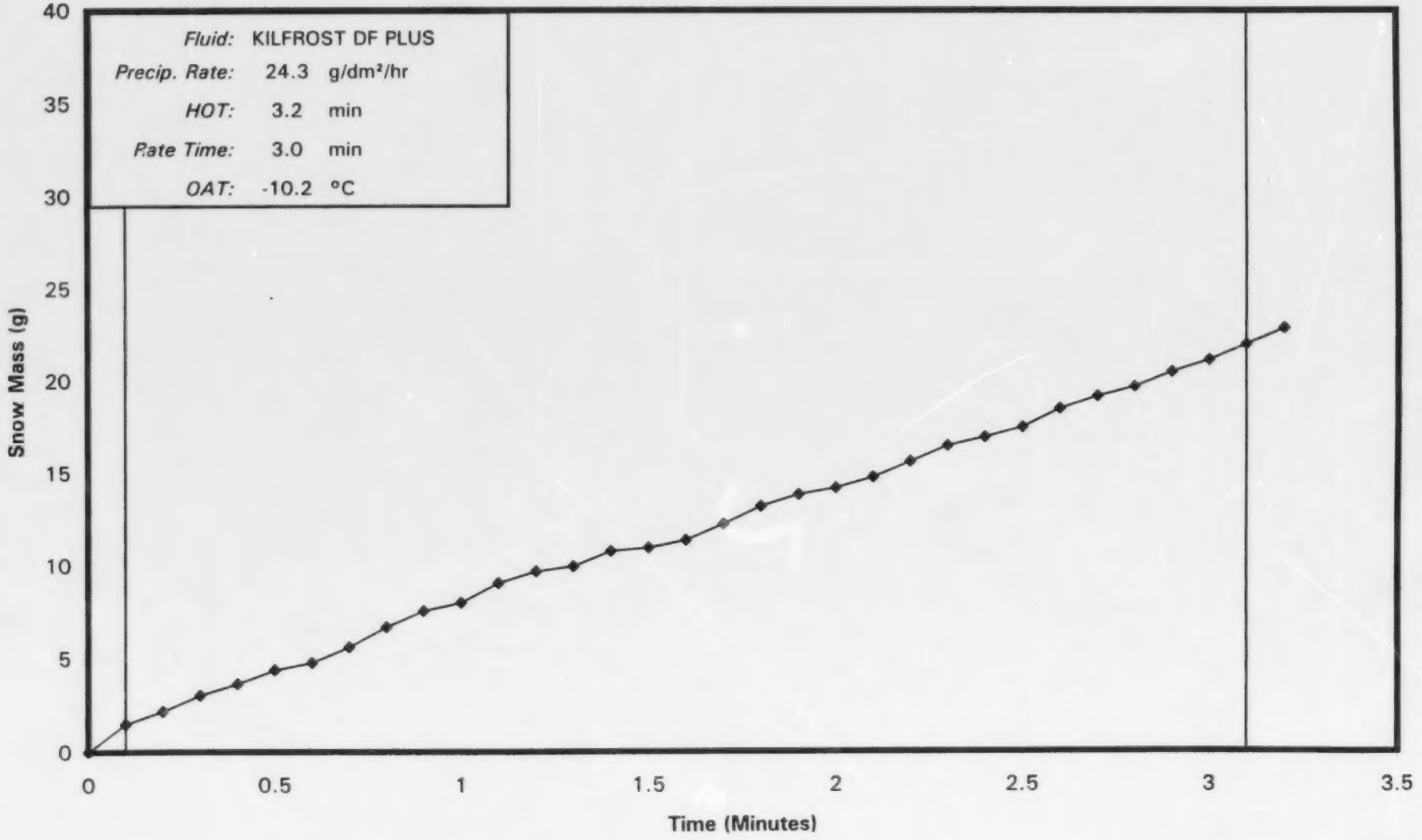


Id_06
9/24/99, 2:48 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 7



Id_07
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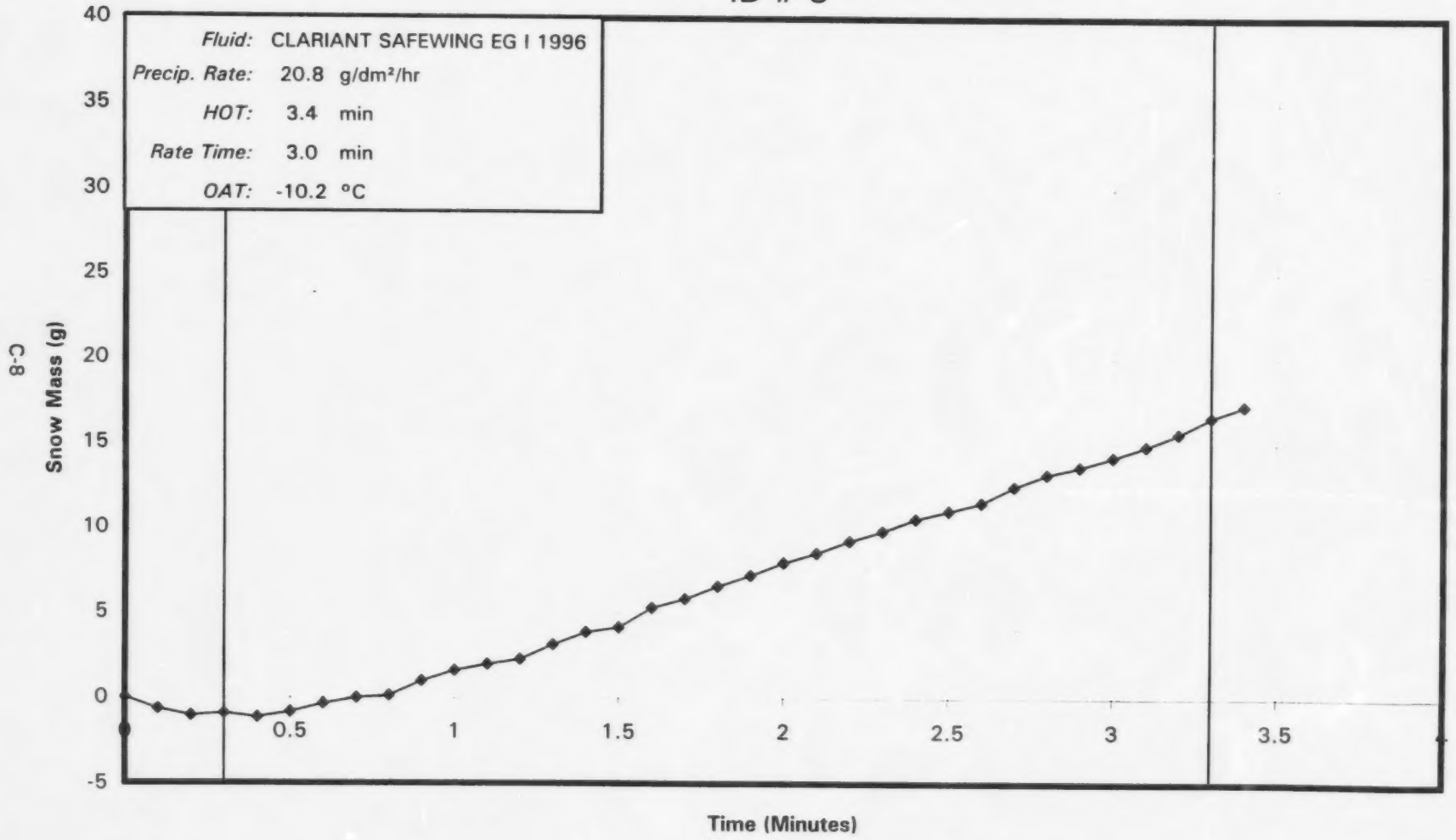
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 8



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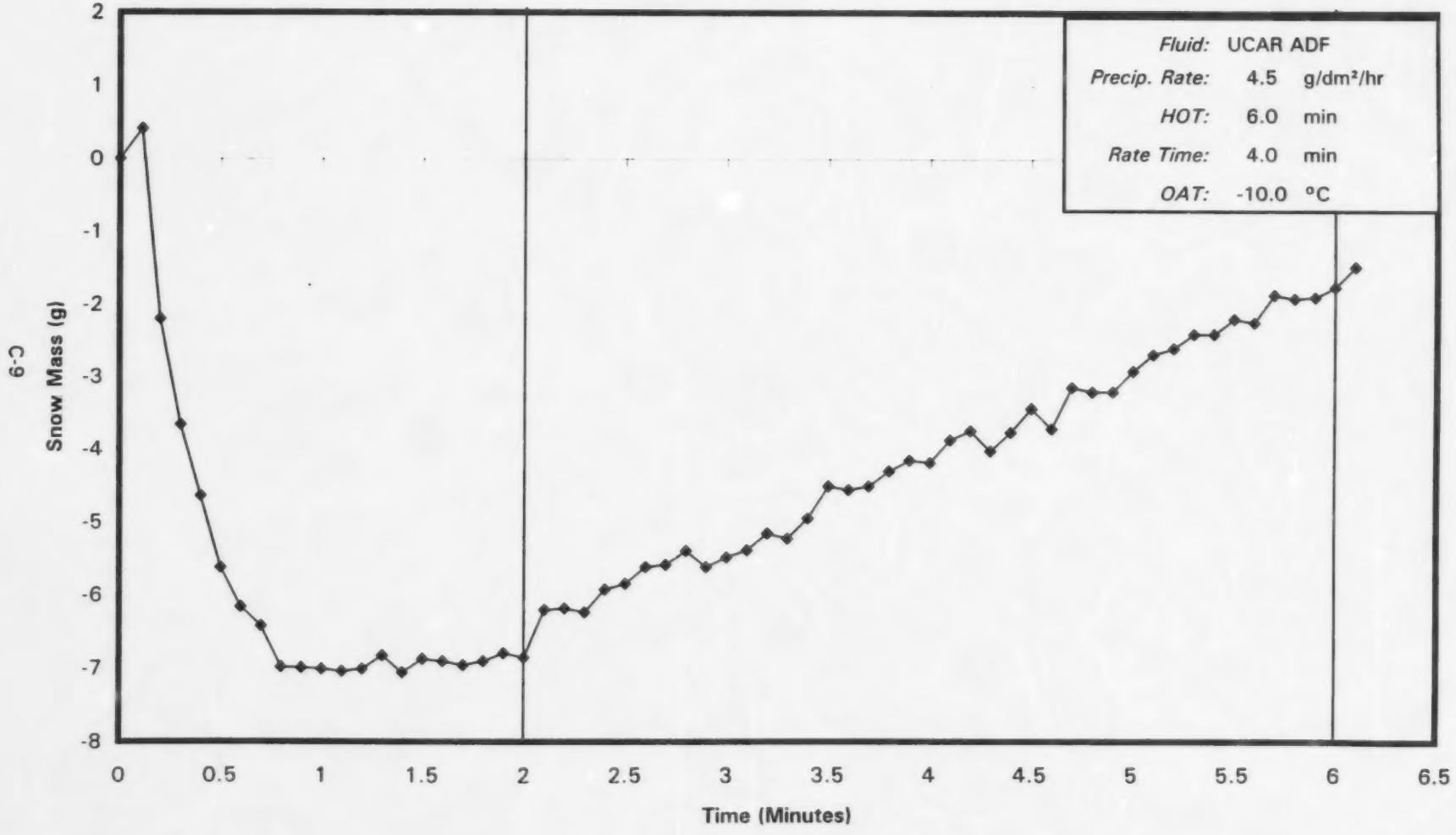
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 10



Id_10
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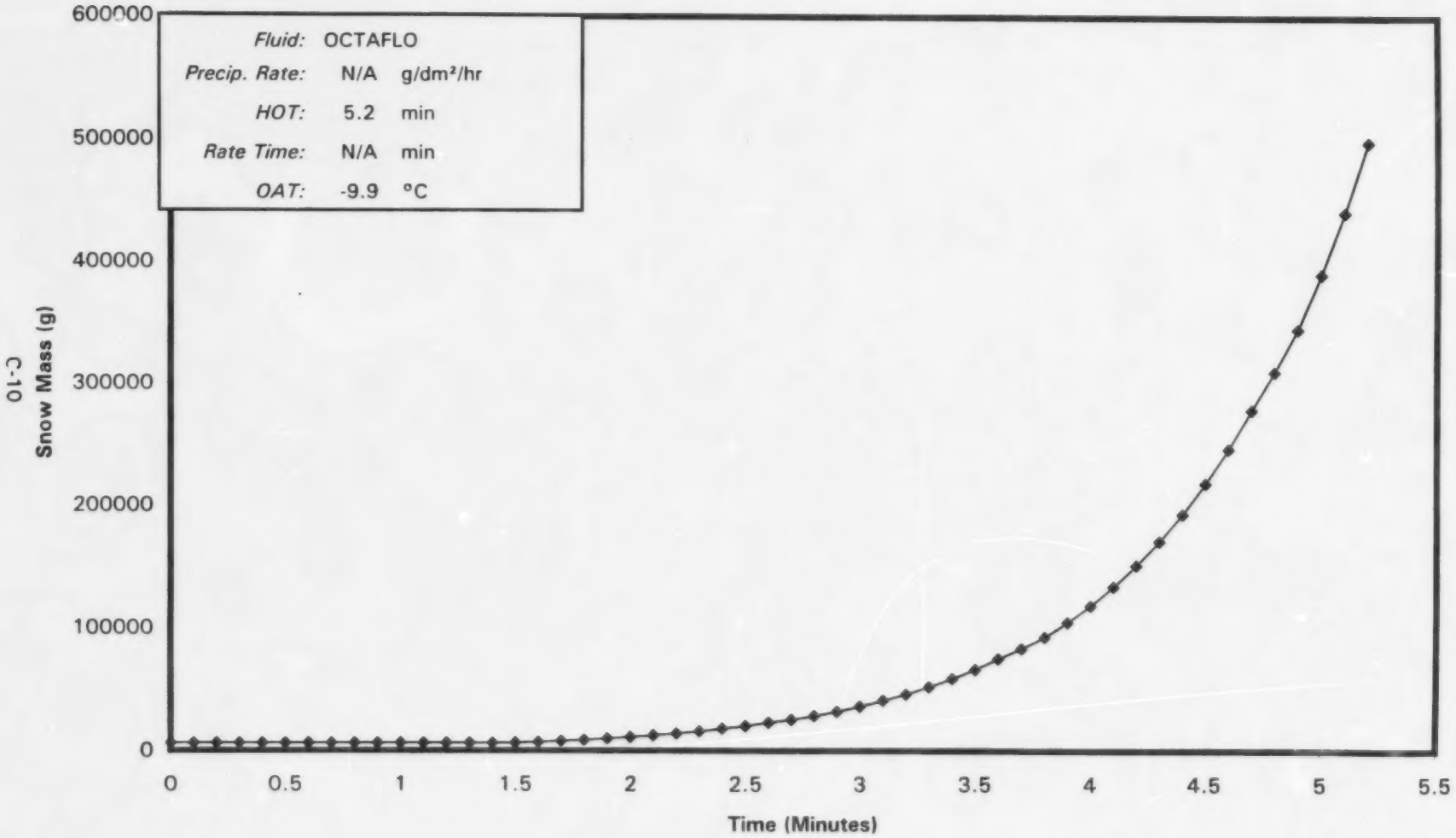
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 11



Id_11
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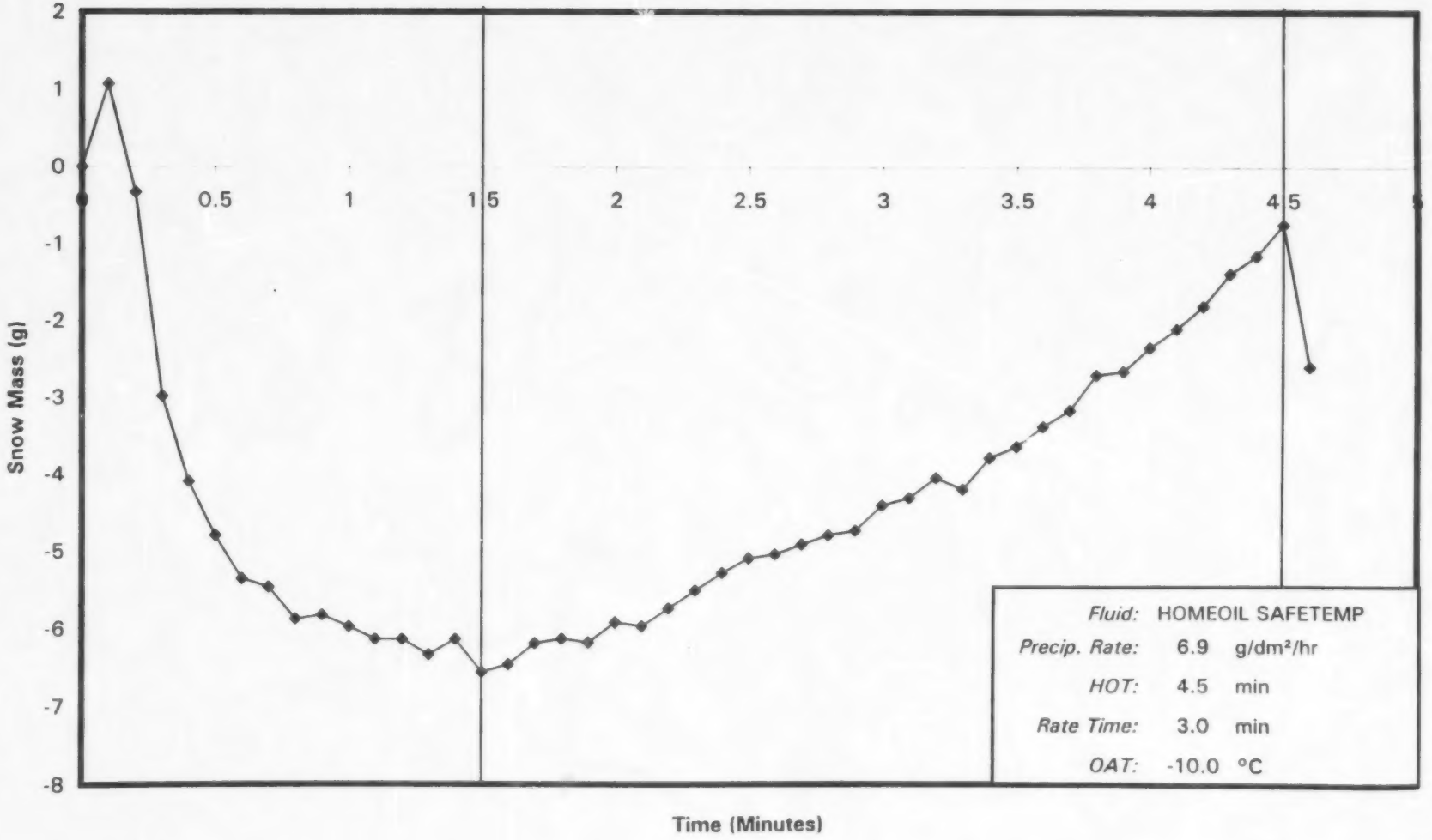
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 12



C-11

Id_12
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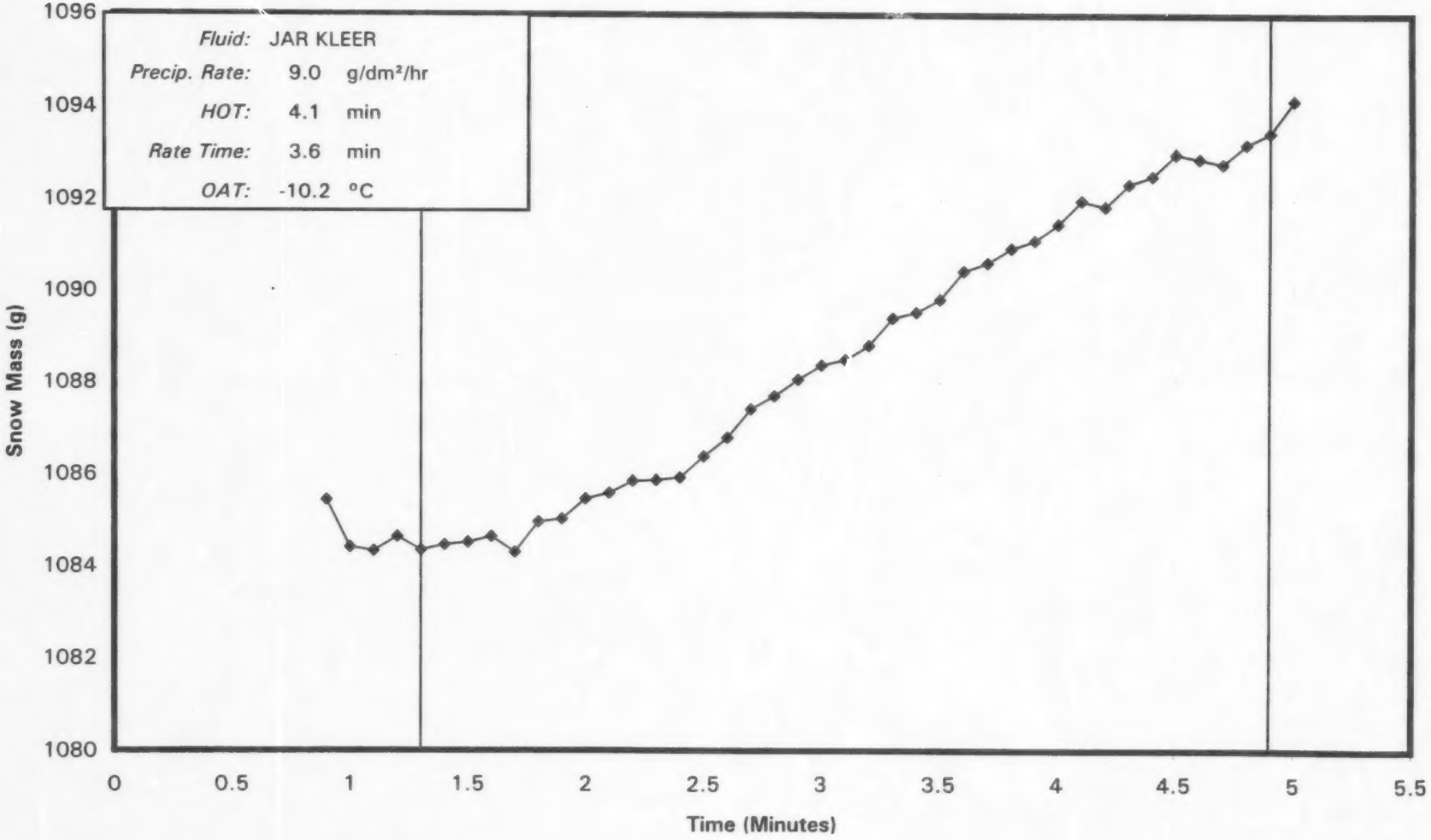
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 14



Id_14
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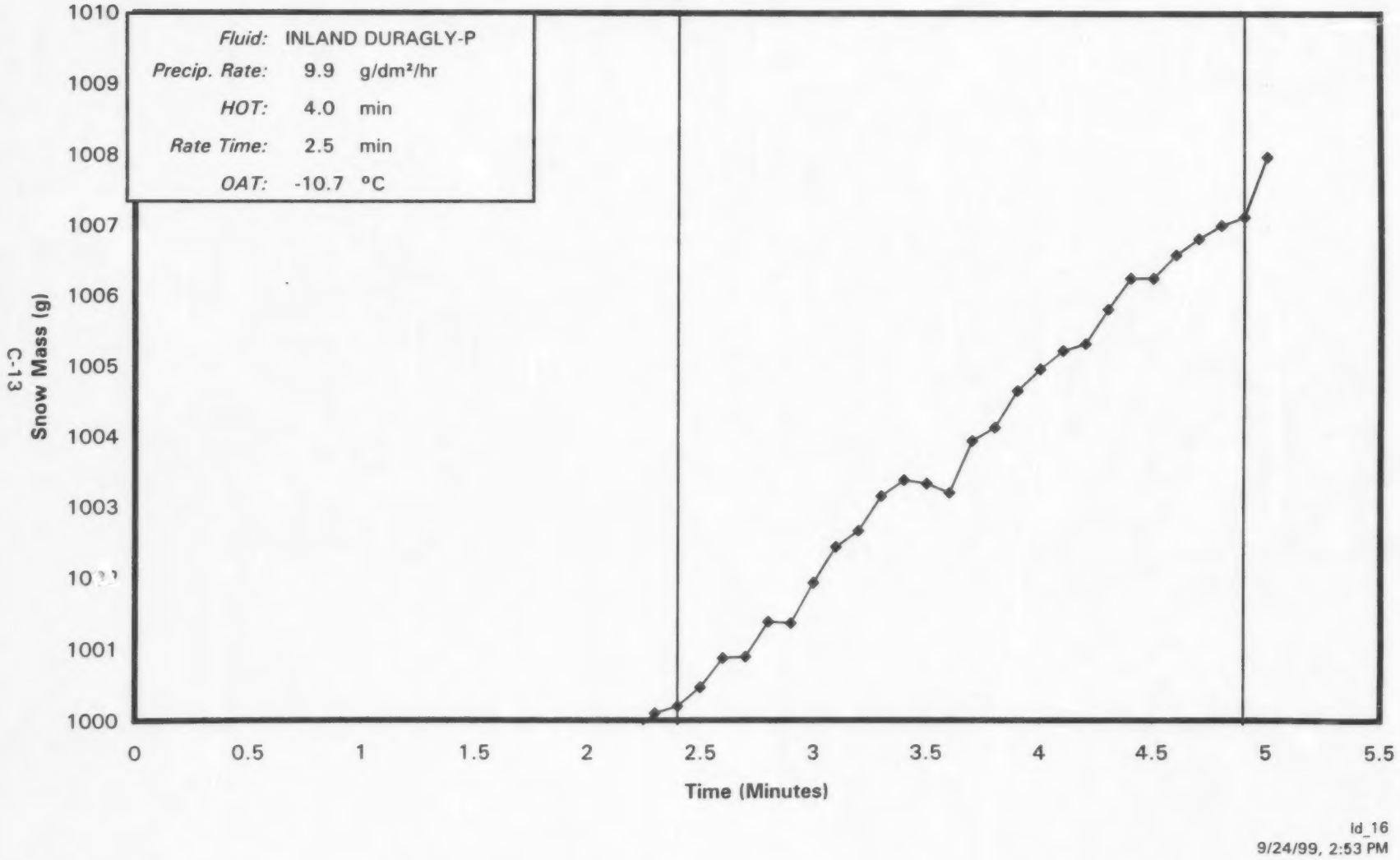
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 16



C-13

Id_16
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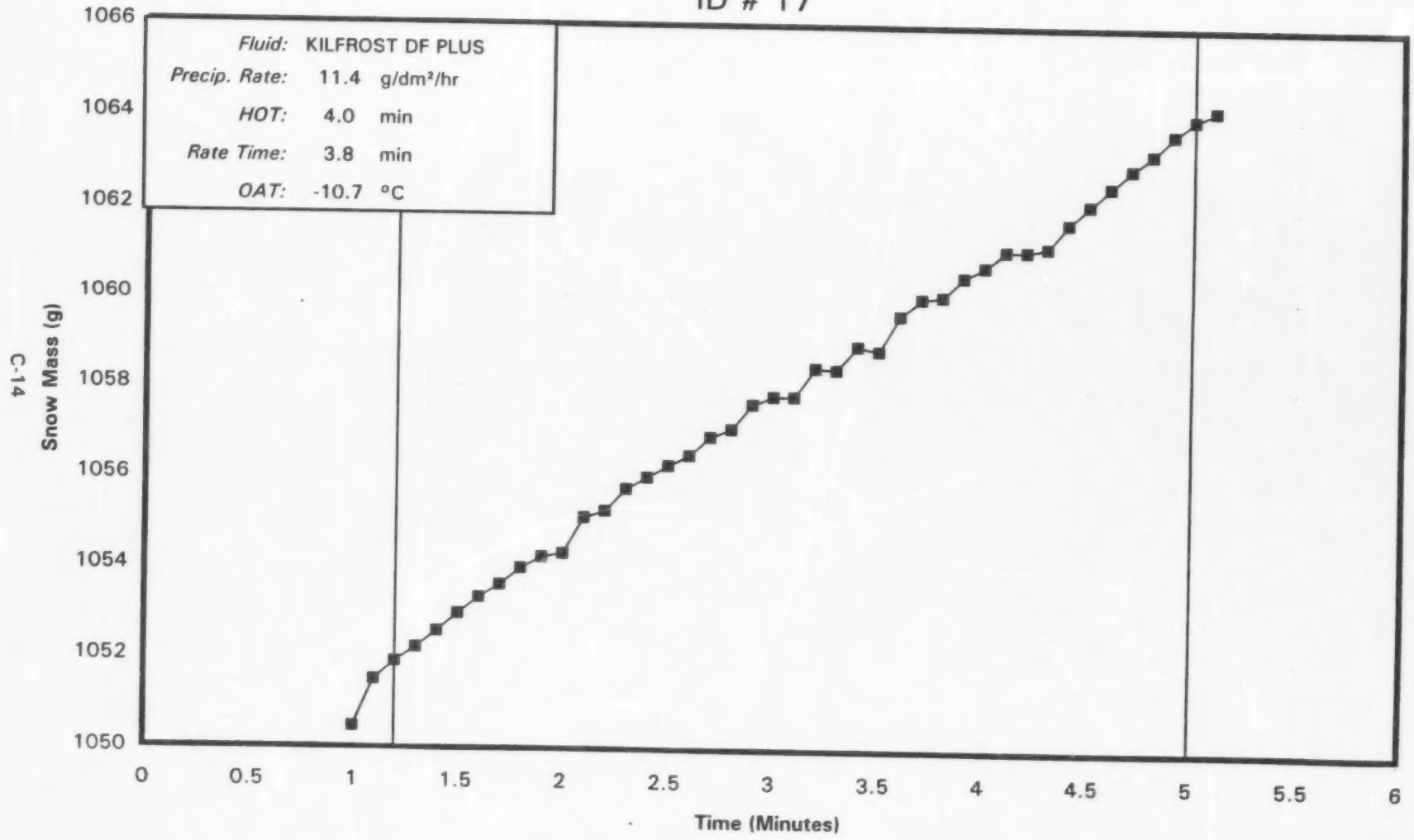
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 17



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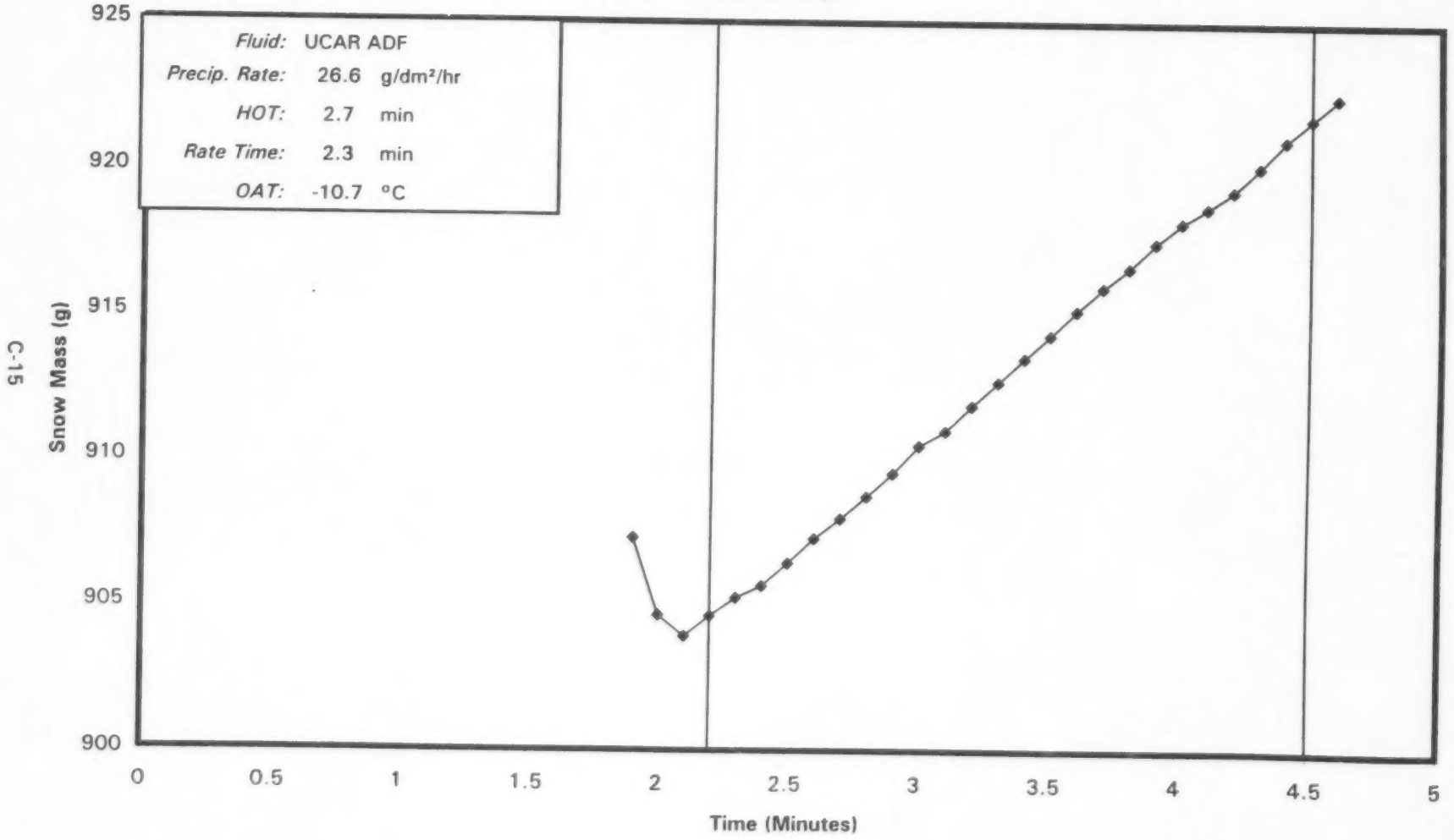
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 18



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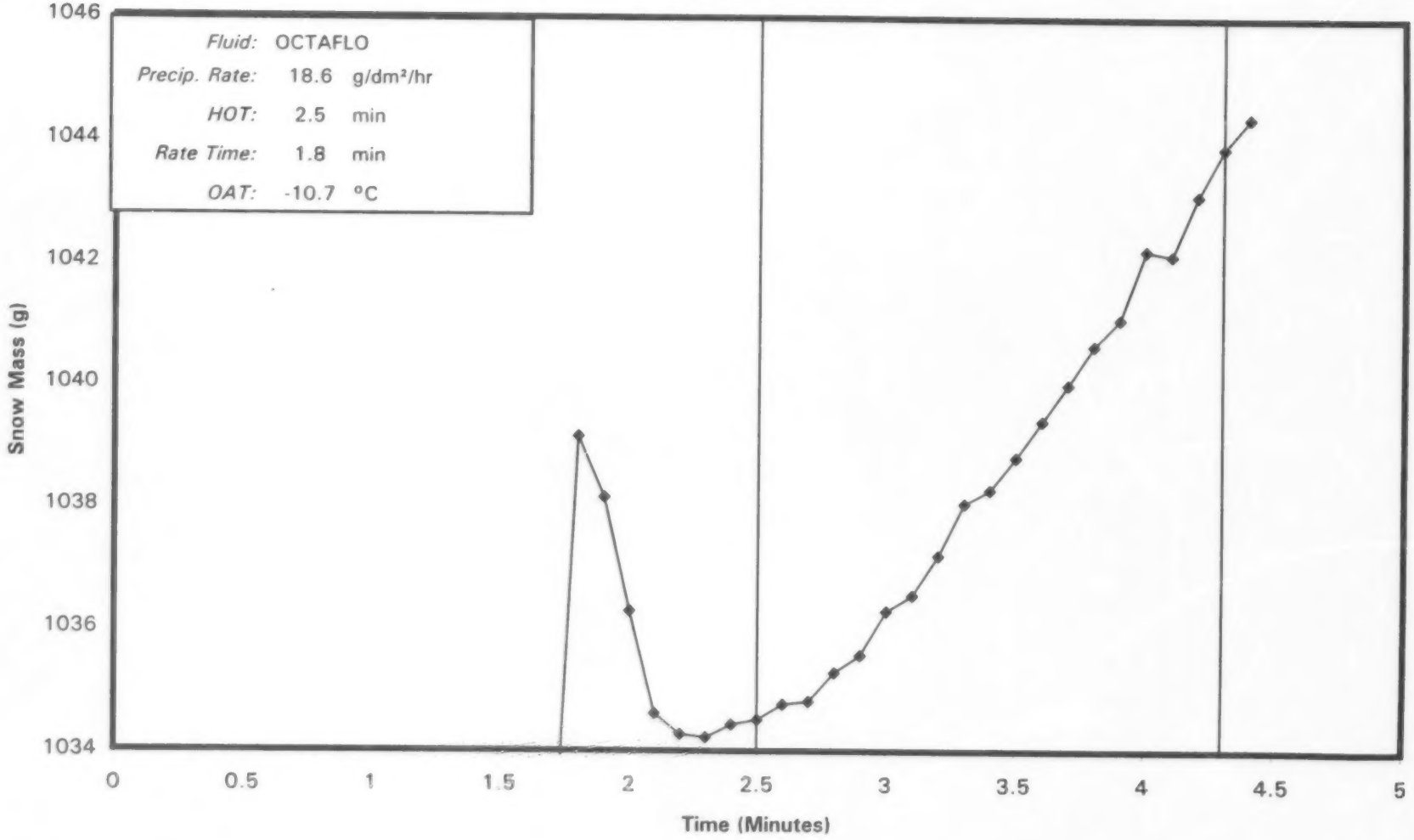
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 19



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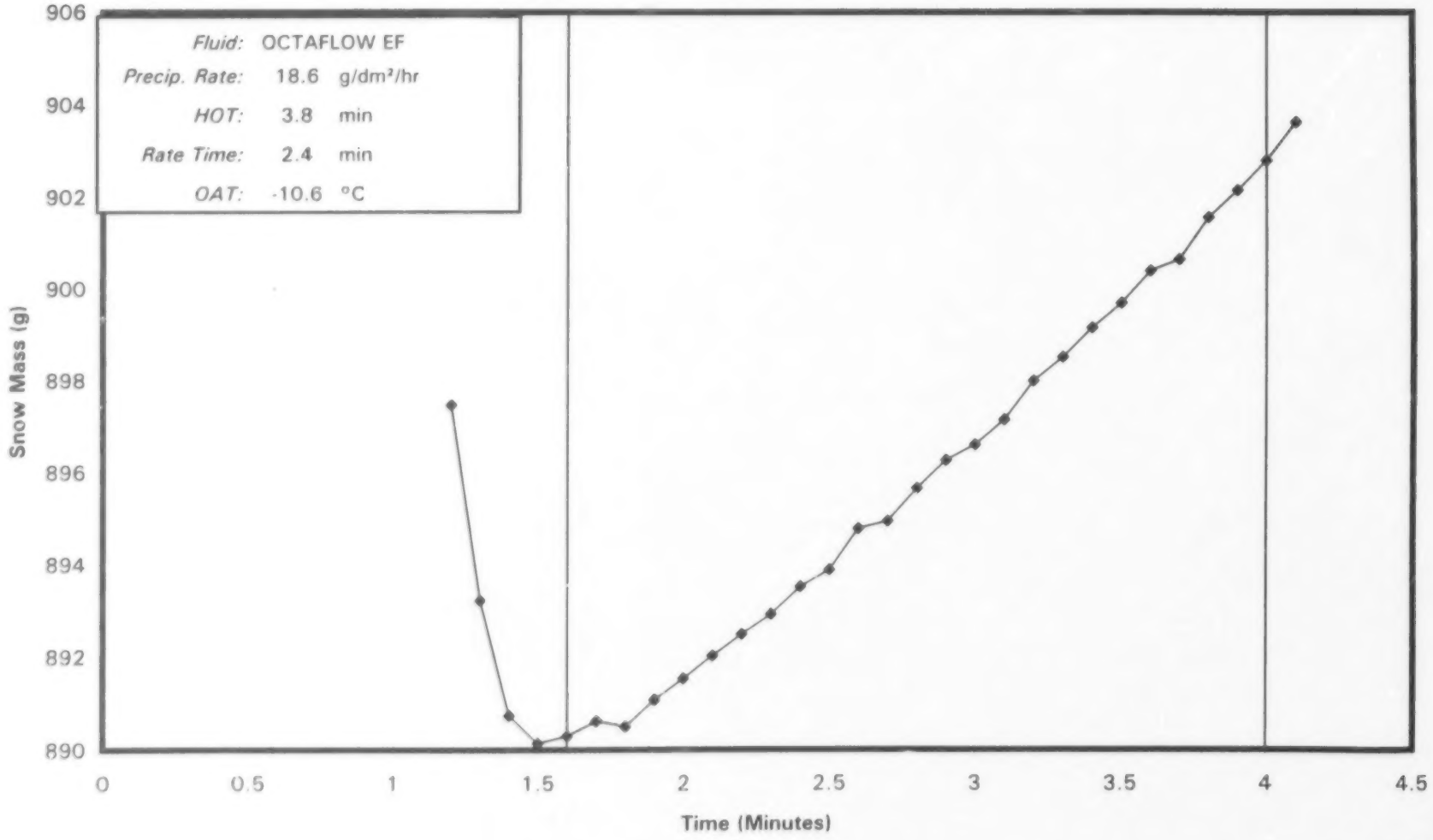
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 20



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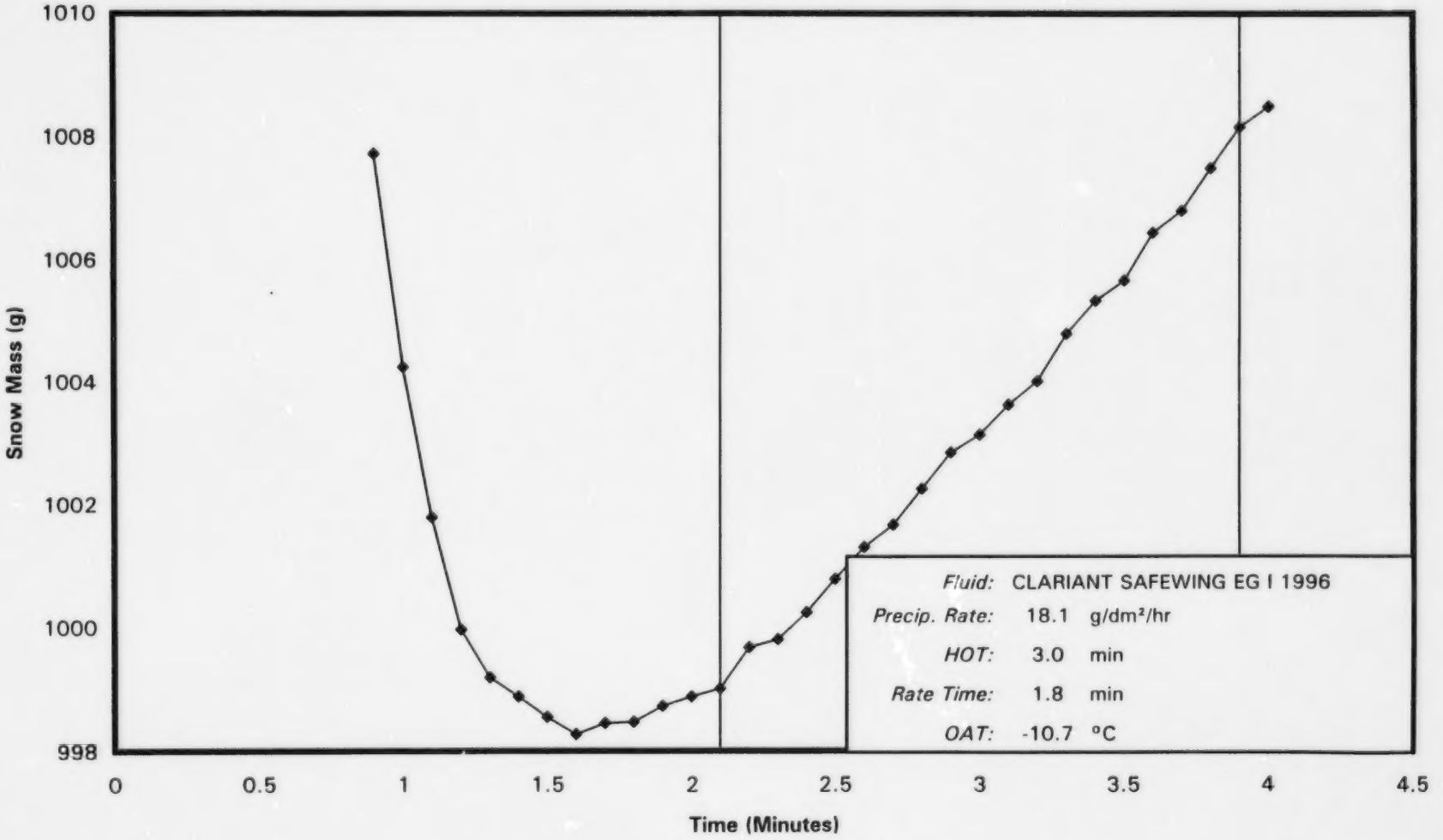
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 21



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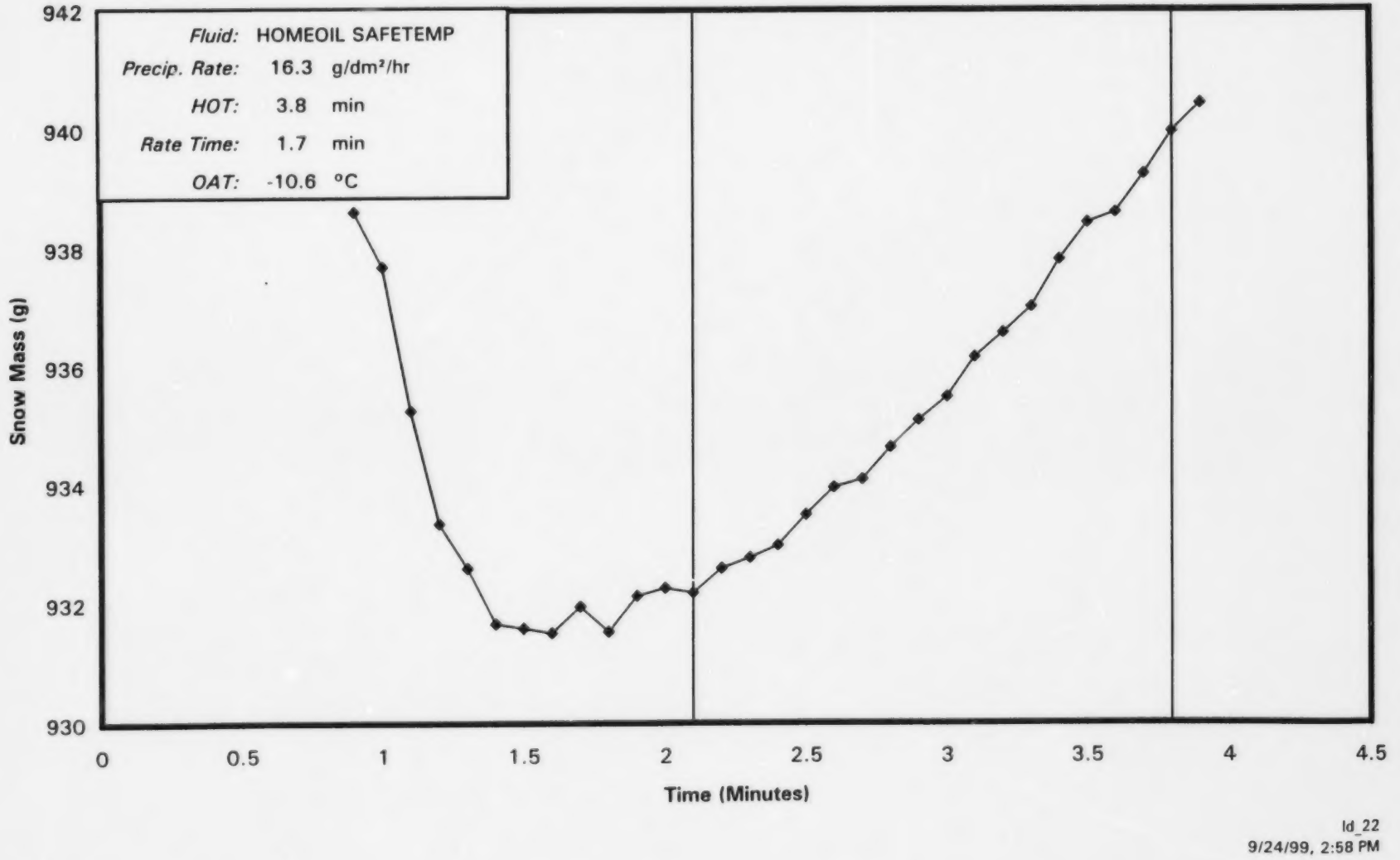
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 22



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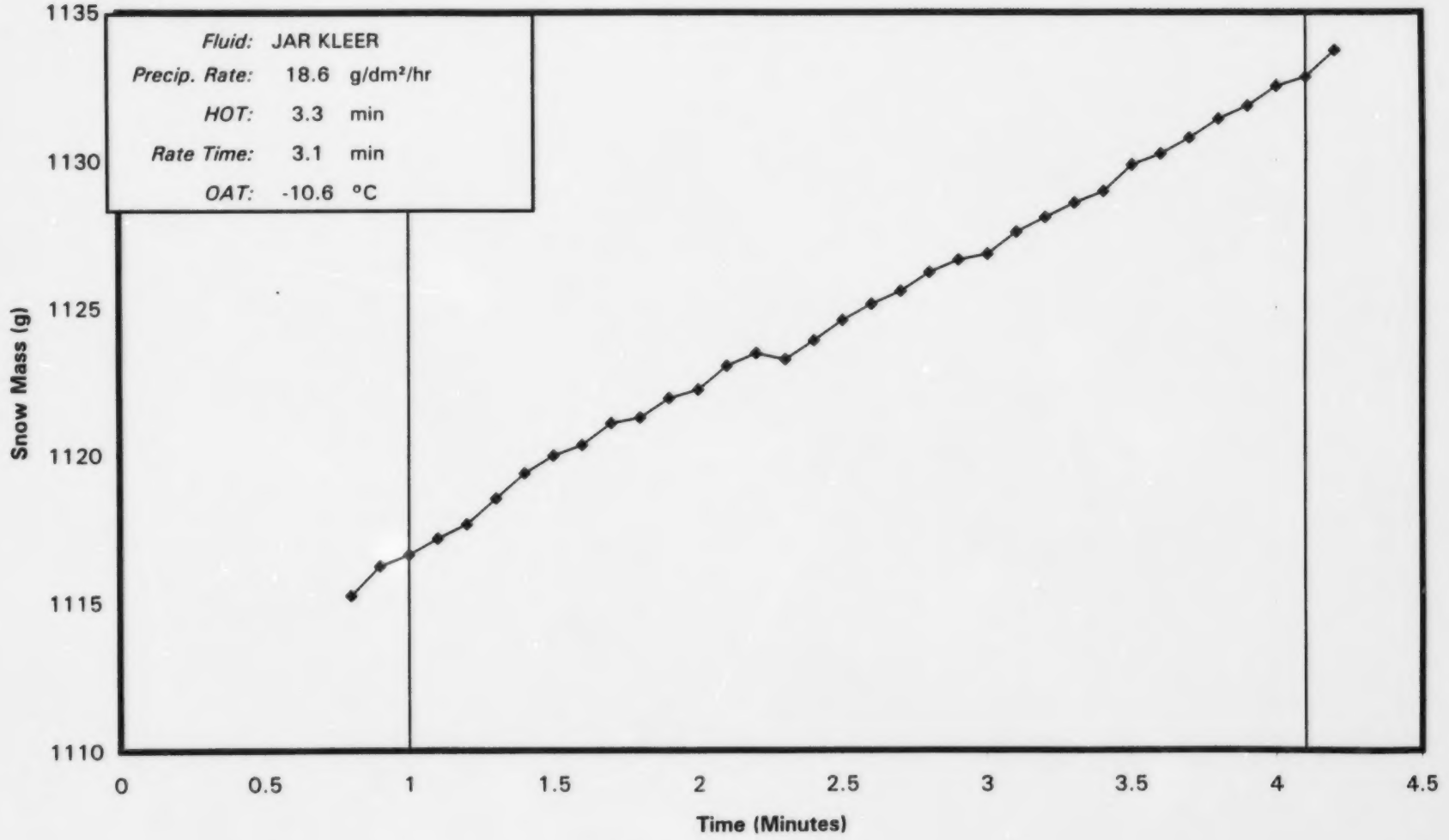
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 23



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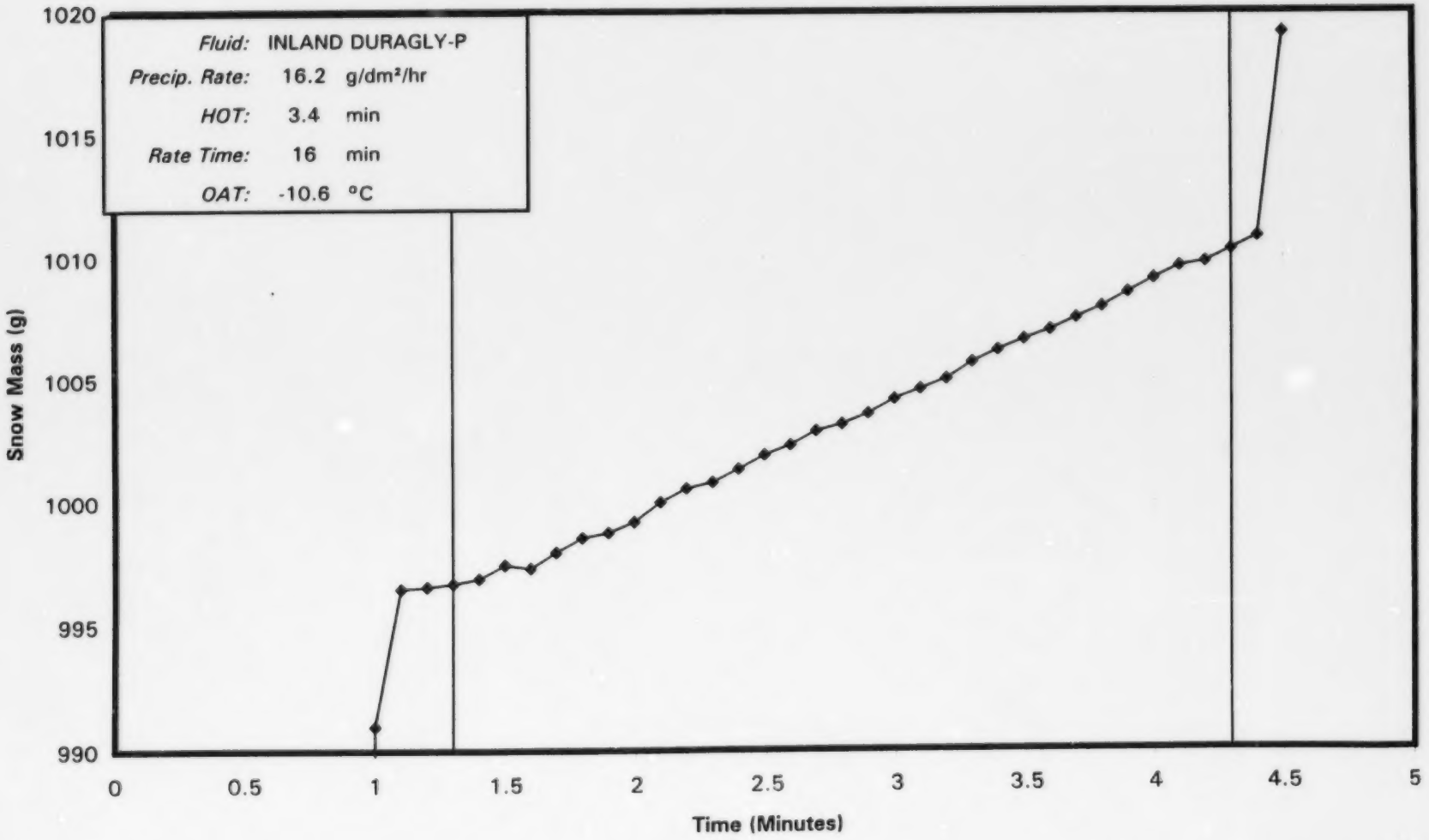
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 24



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NCAR SNOW MAKER

SNOW MASS ACCUMULATION

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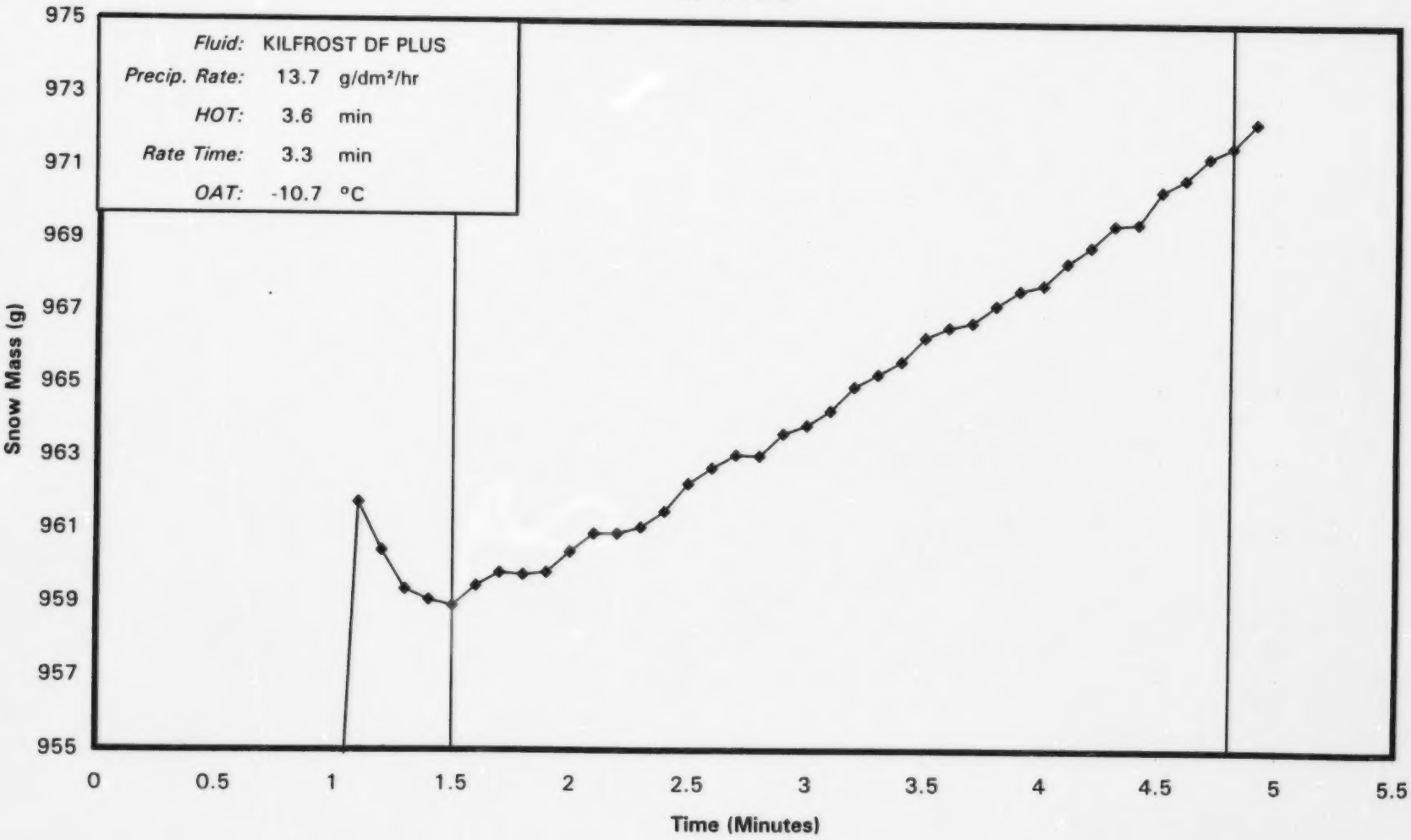

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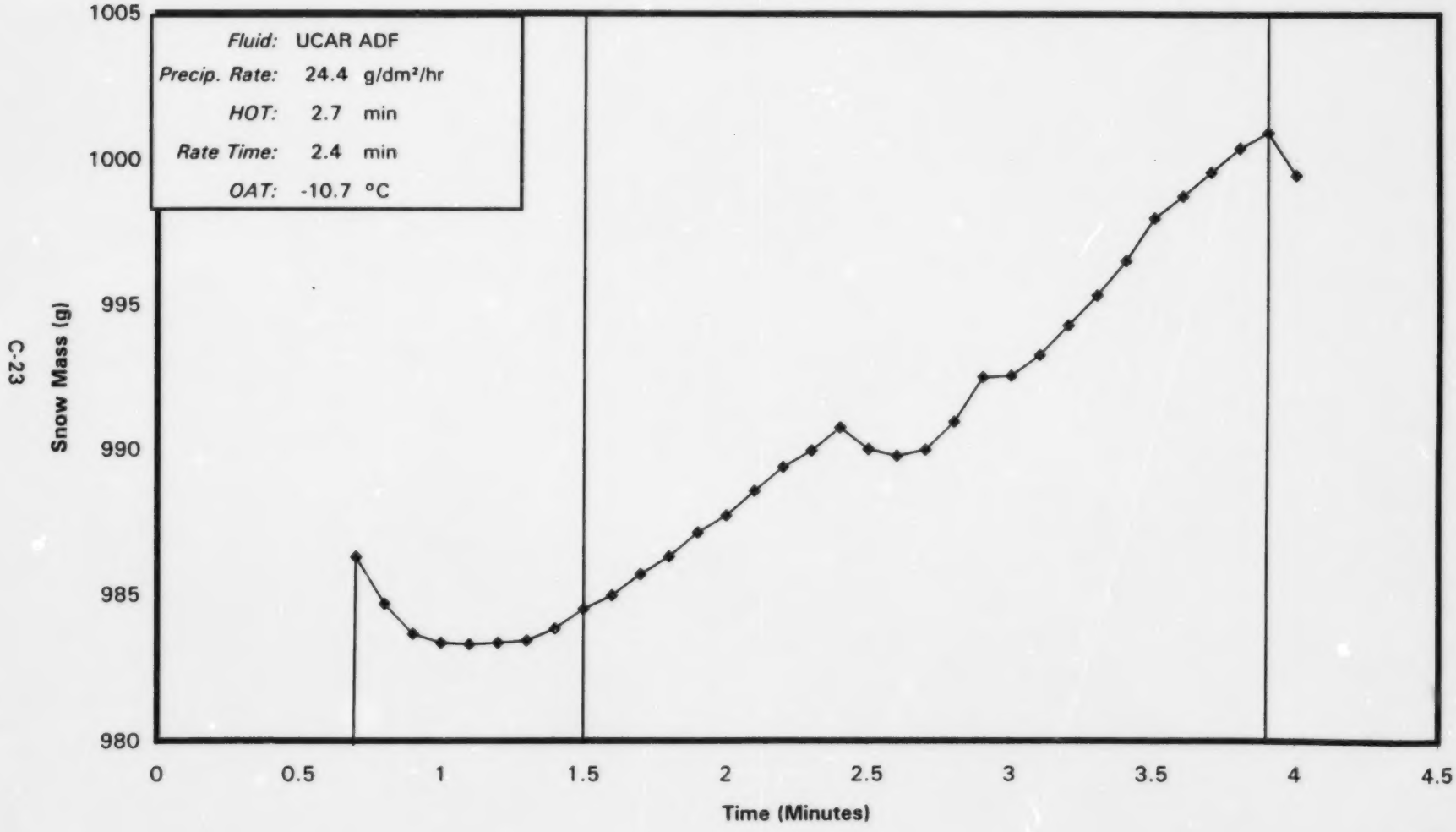
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 26



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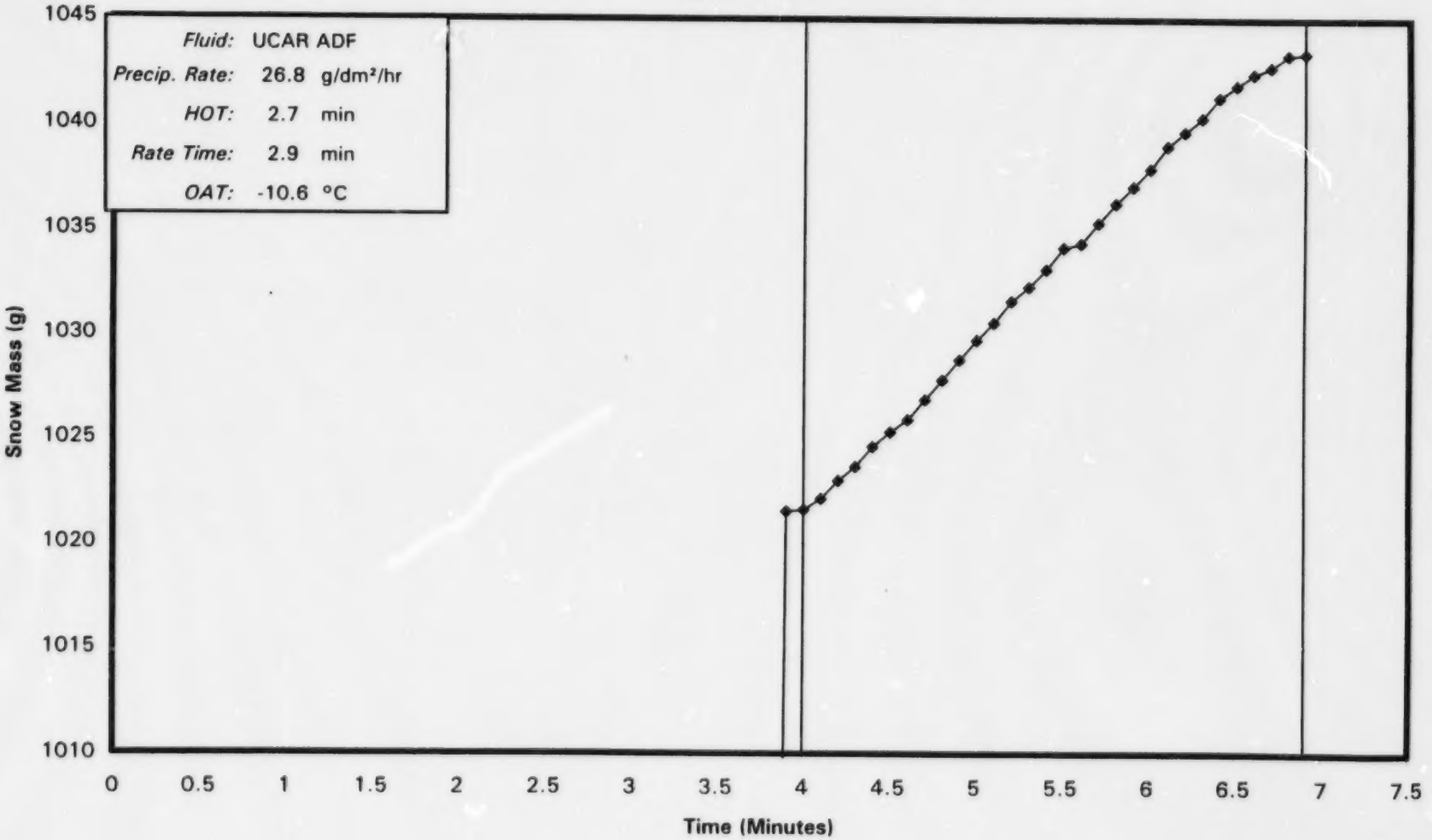
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 27



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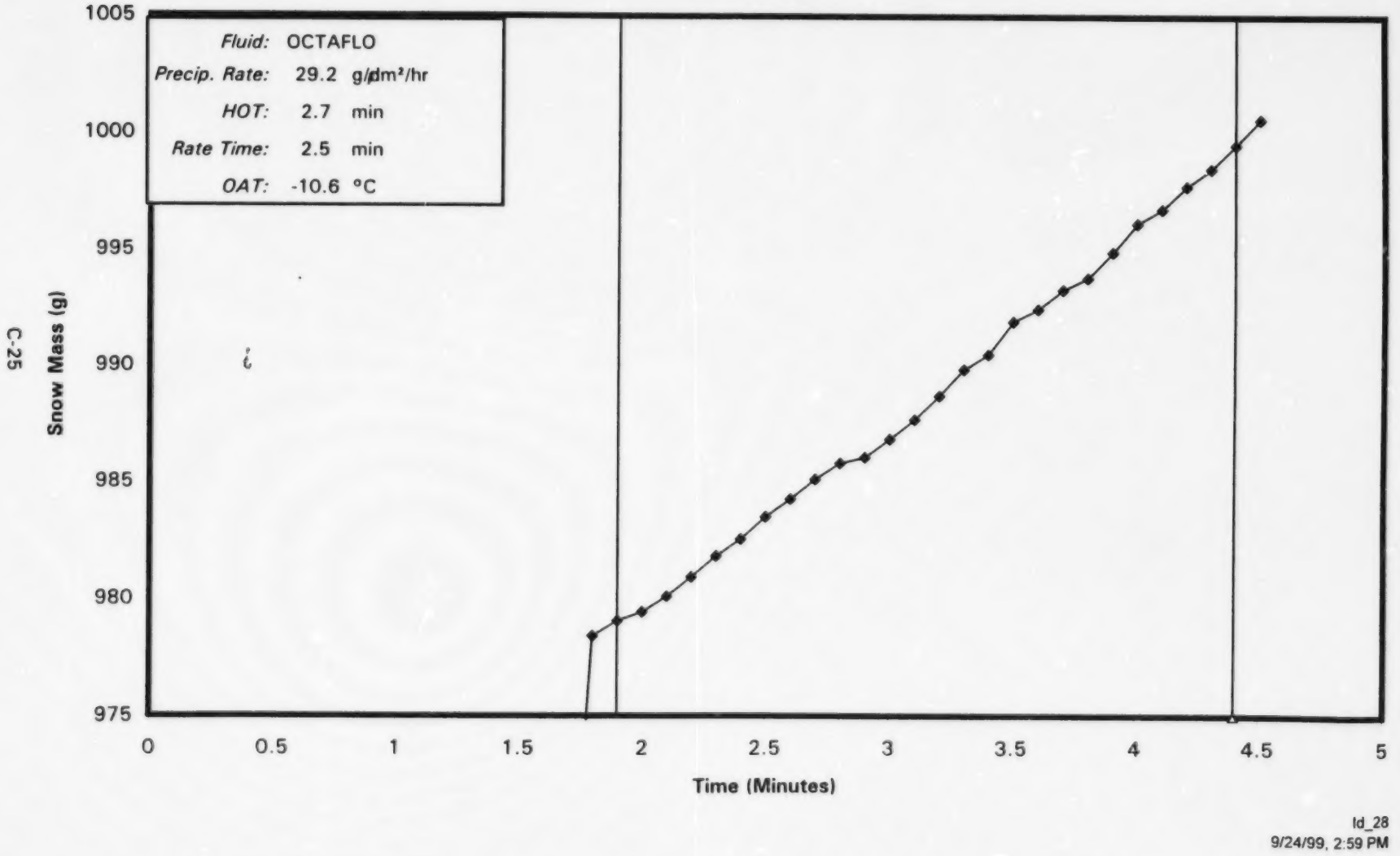
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 28



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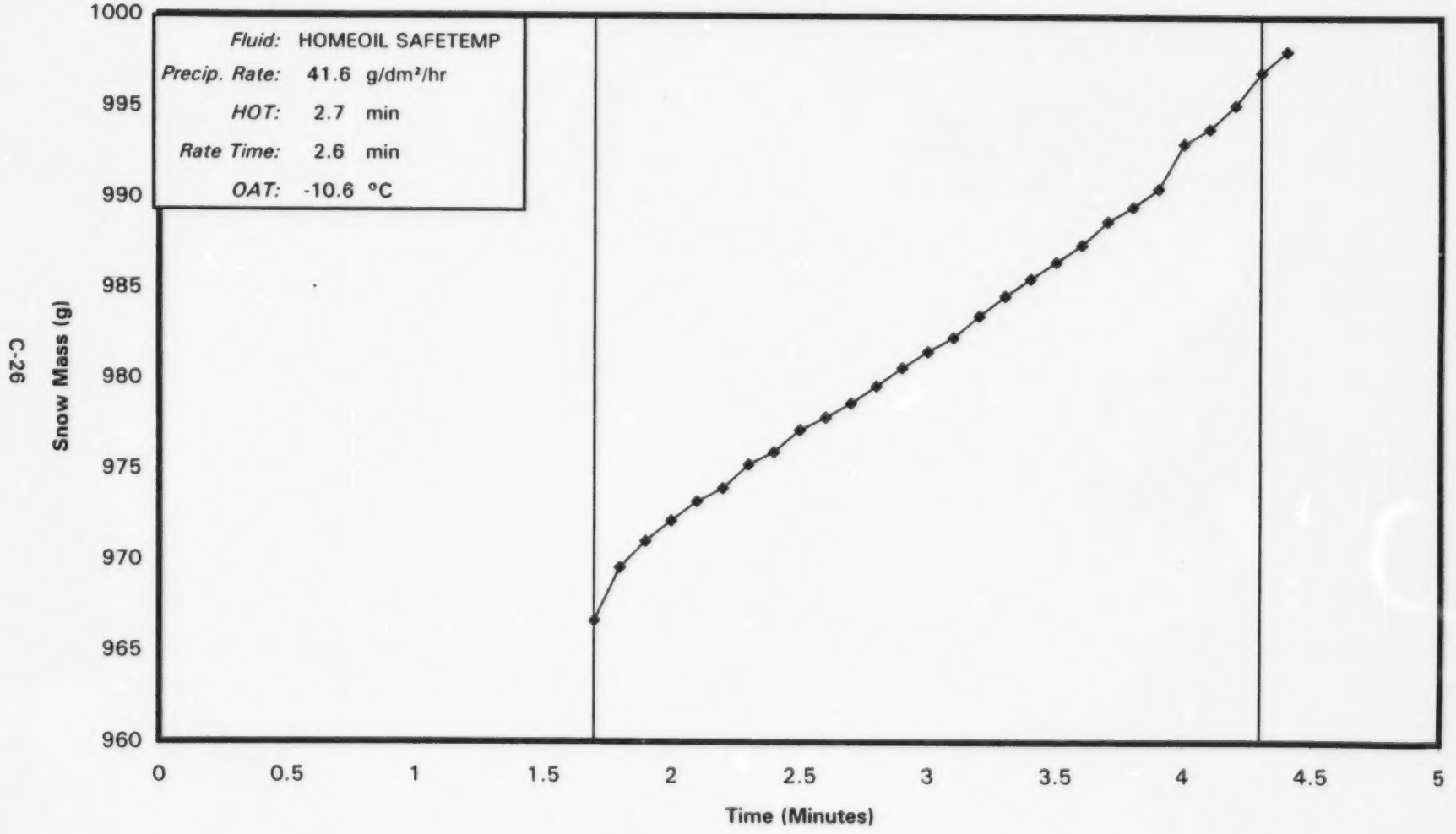
9/24/99, 2:59 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 29



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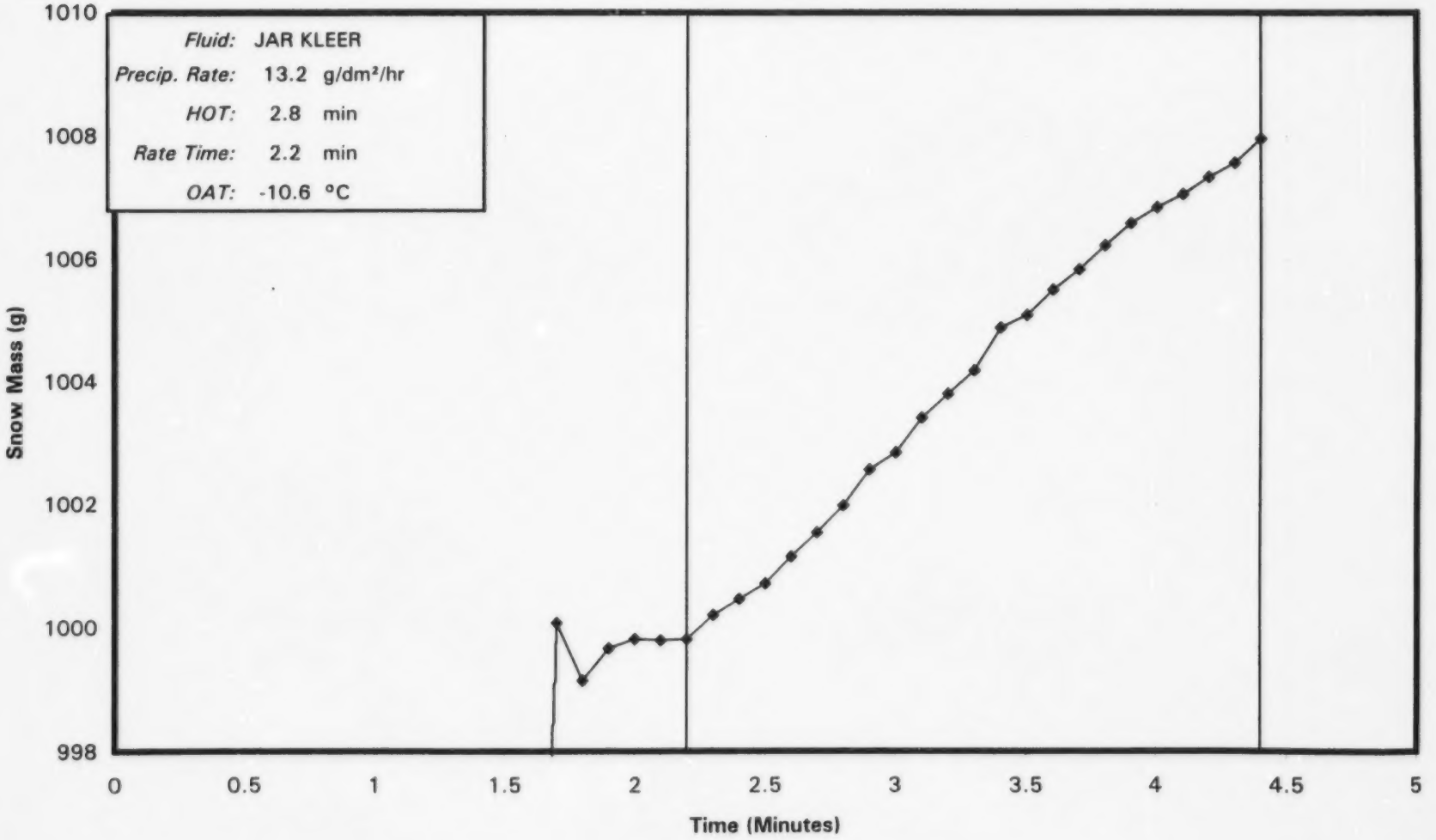
9/24/99, 3:00 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 30

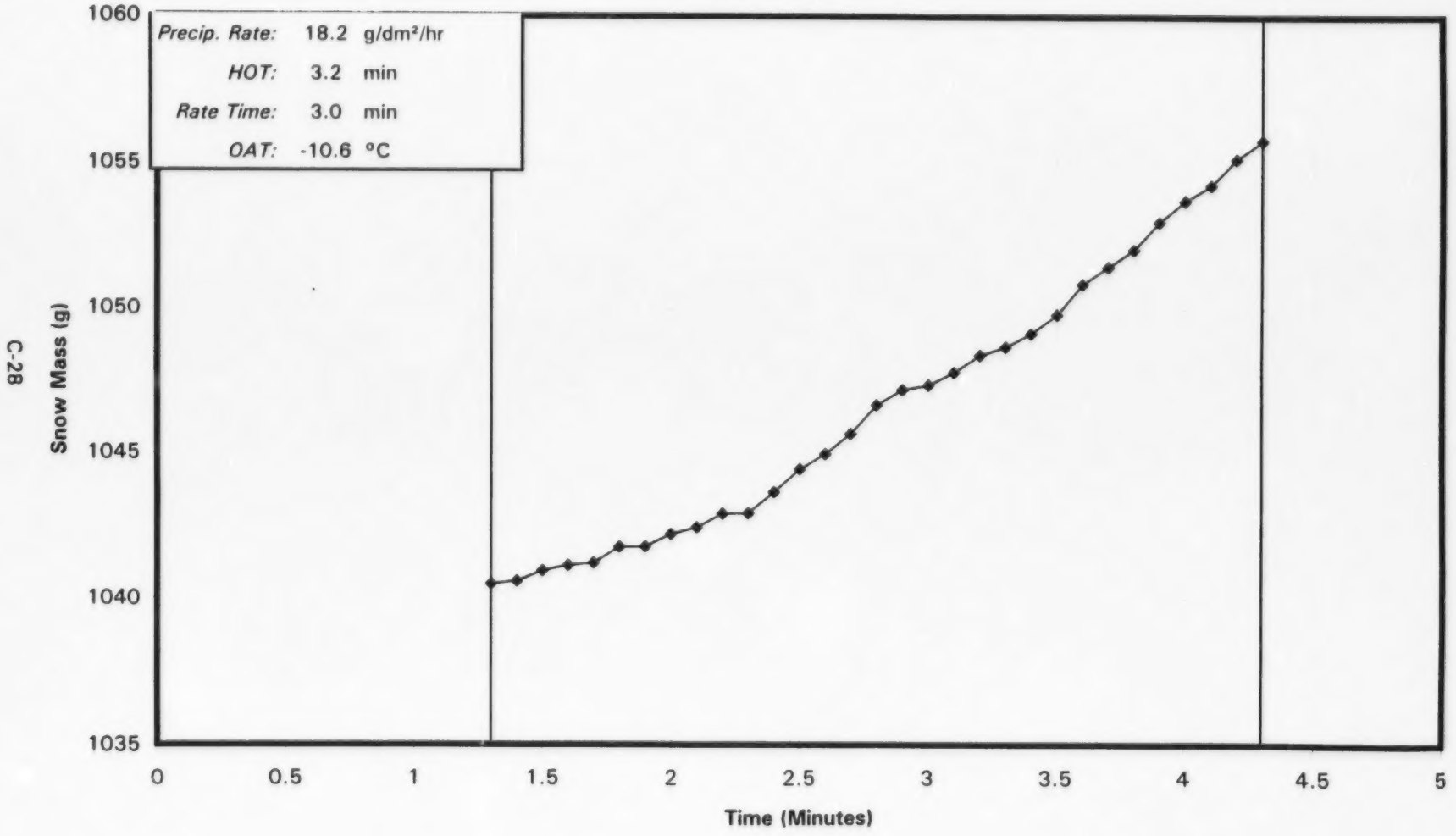


Id_30
9/24/99, 3:07 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 31



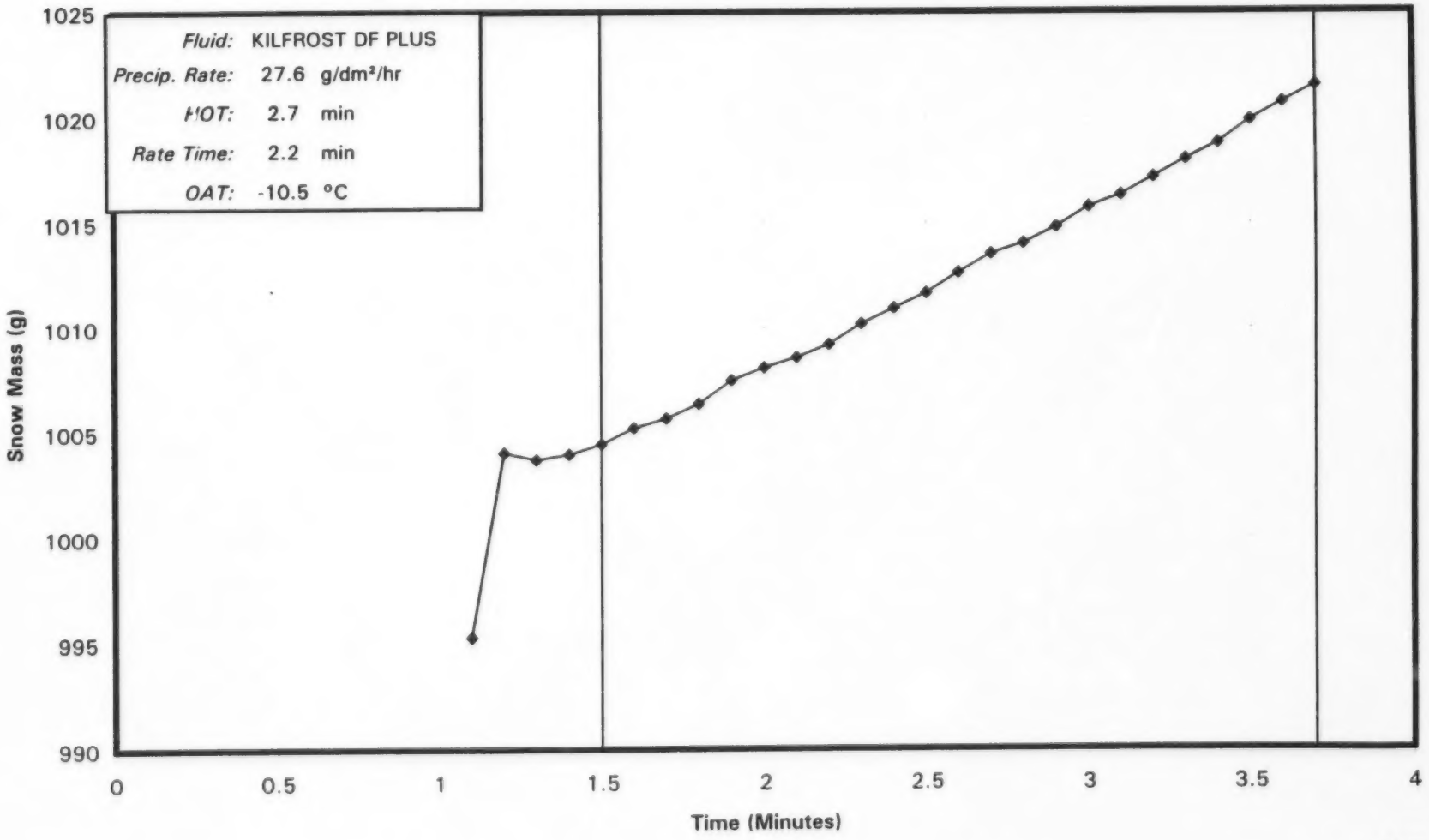
C-28

Id_31
9/24/99, 3:03 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 32

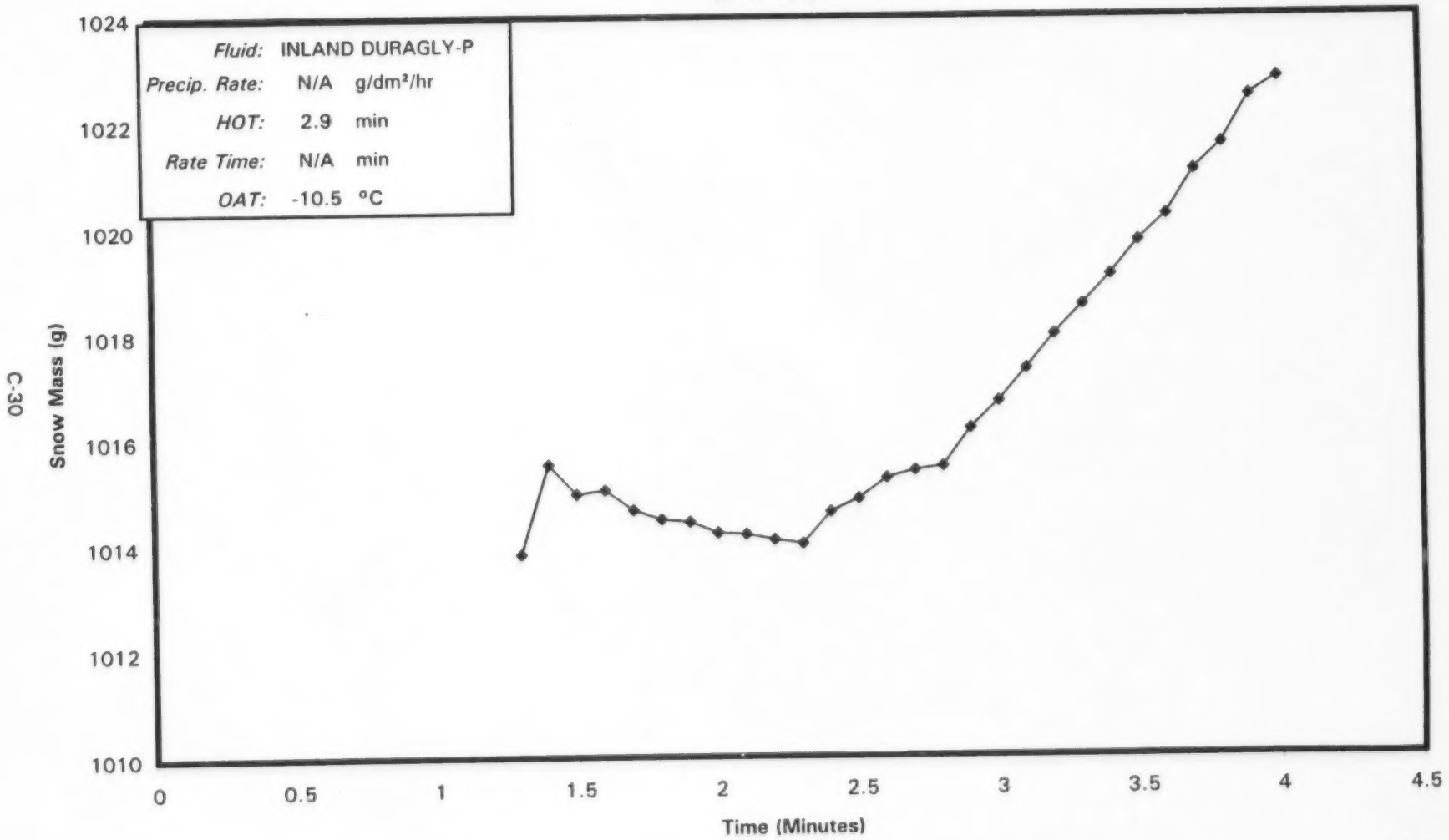


Id_32
9/24/99, 3:01 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 33

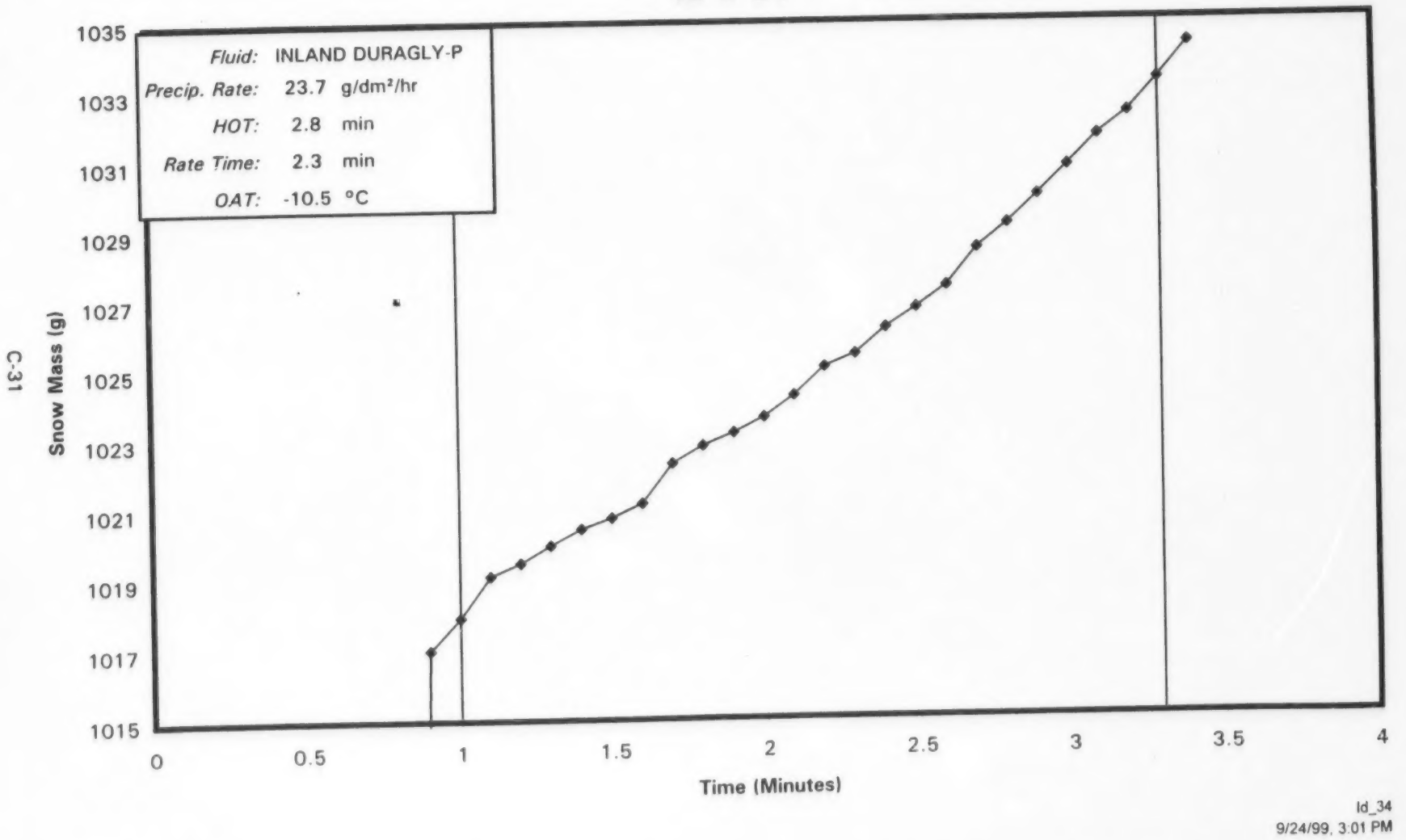


Id_33
9/24/99, 3:03 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 34

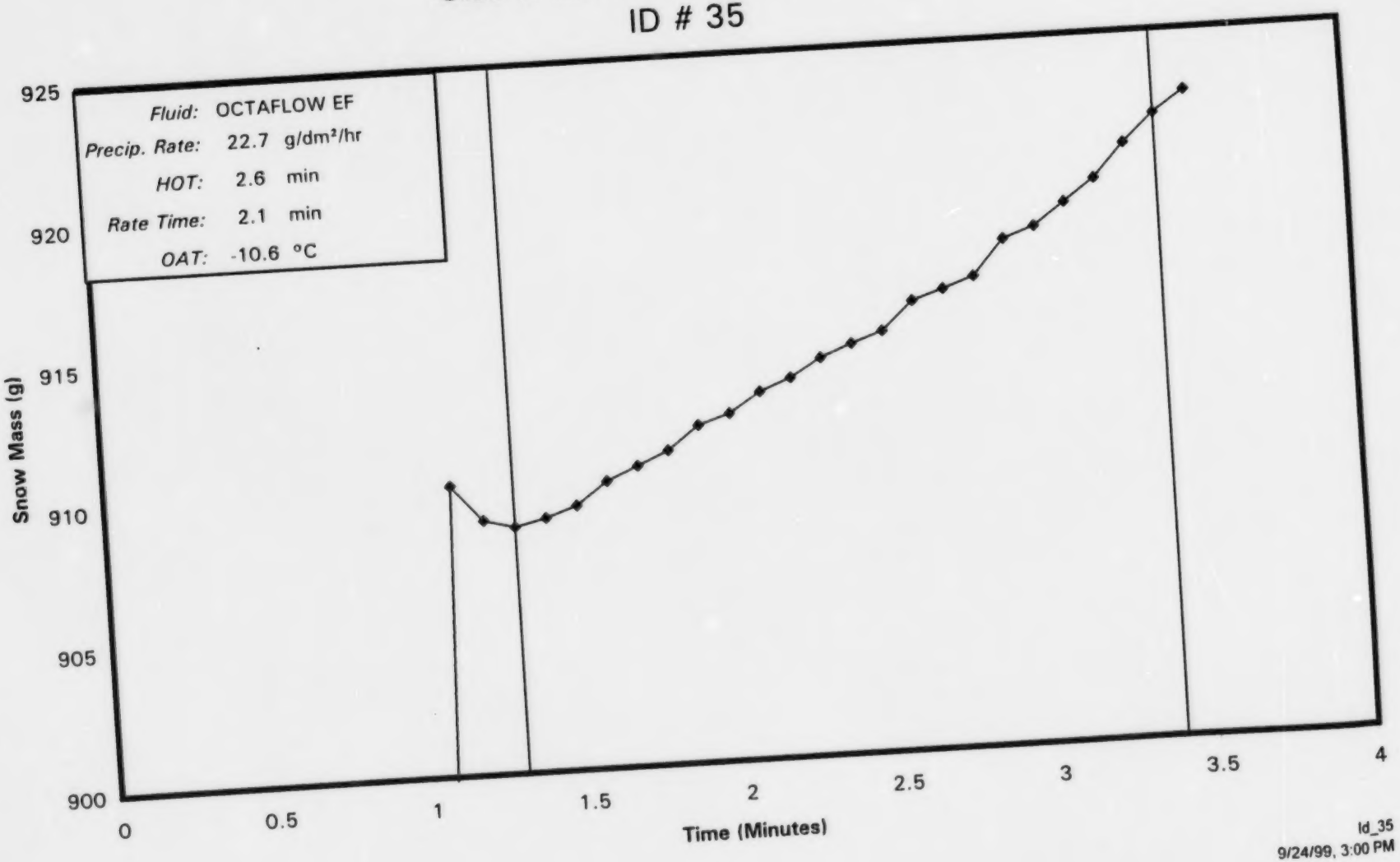


Id_34
9/24/99, 3:01 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 35



NCAR SNOW MAKER

SNOW MASS ACCUMULATION

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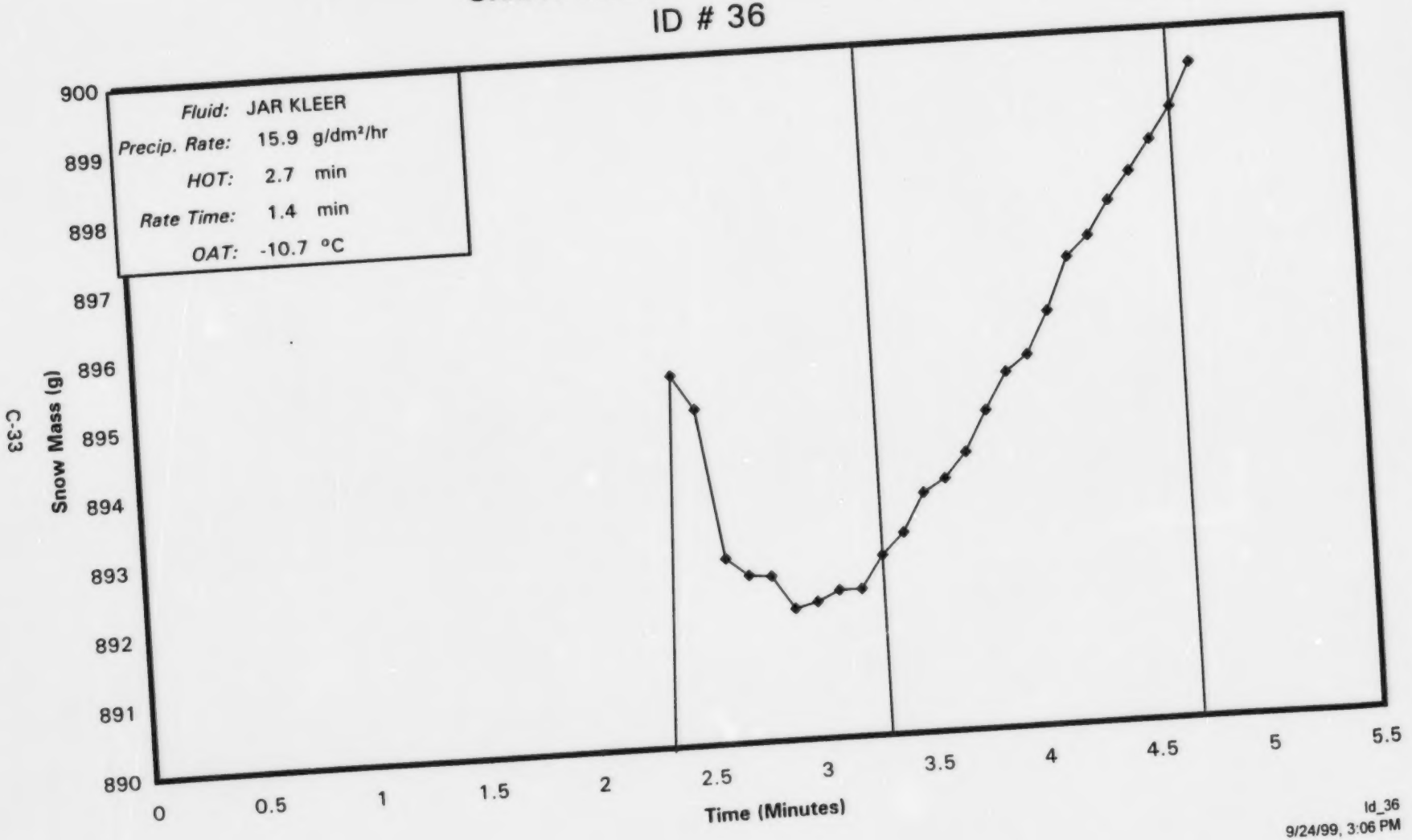
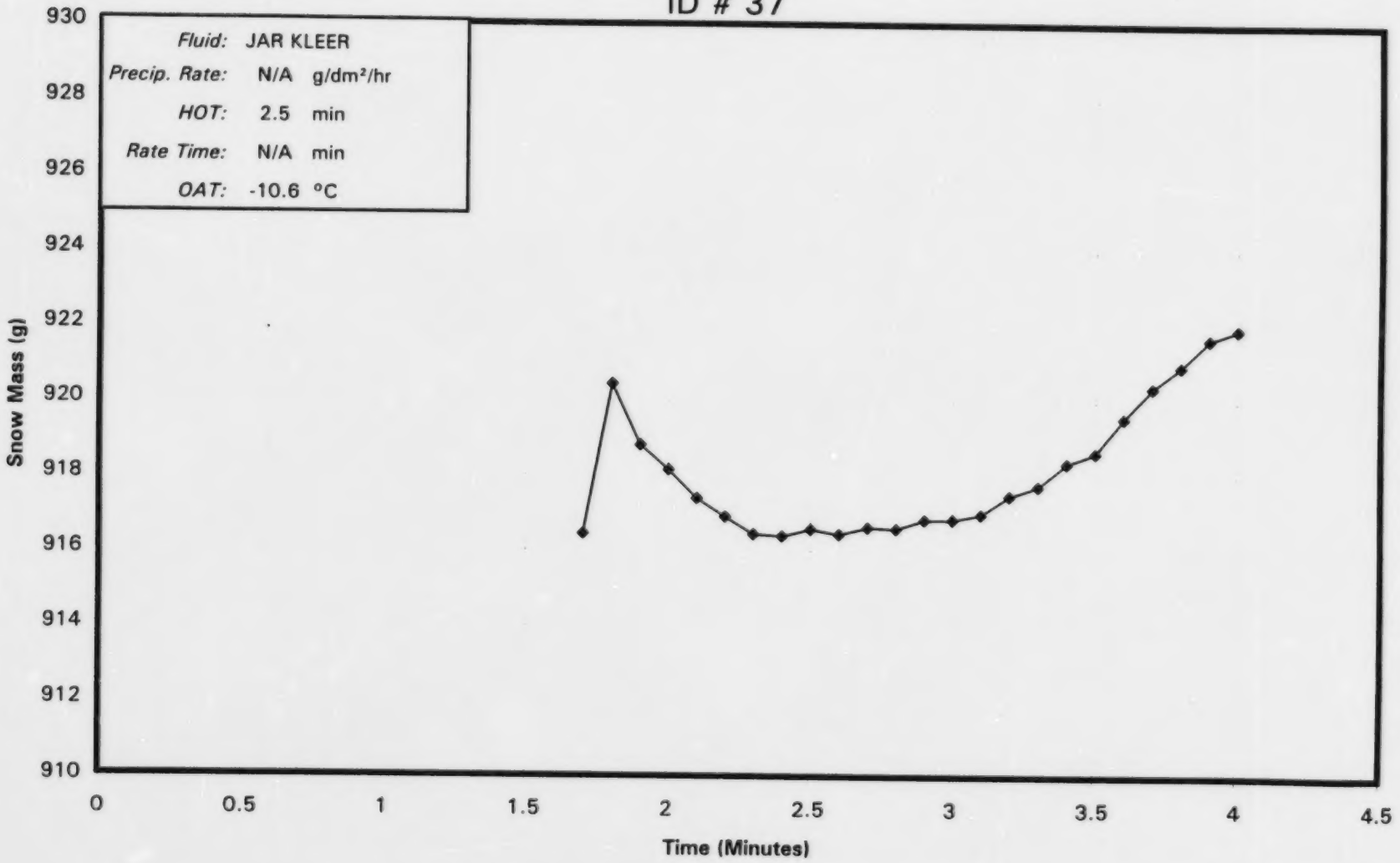


Id_36
9/24/99, 3:06 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 37

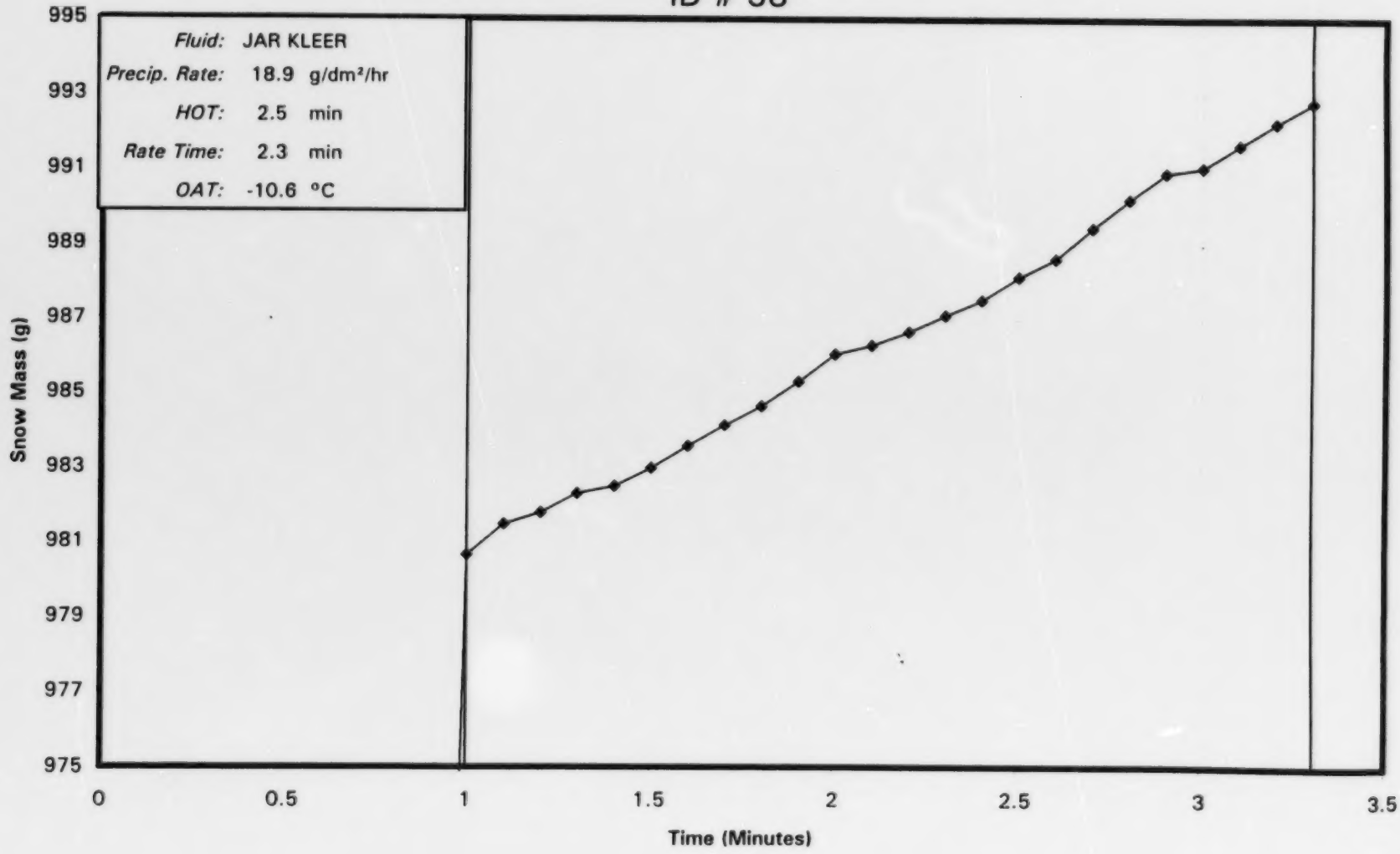


Id_37
9/24/99, 3:05 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 38



Id_38
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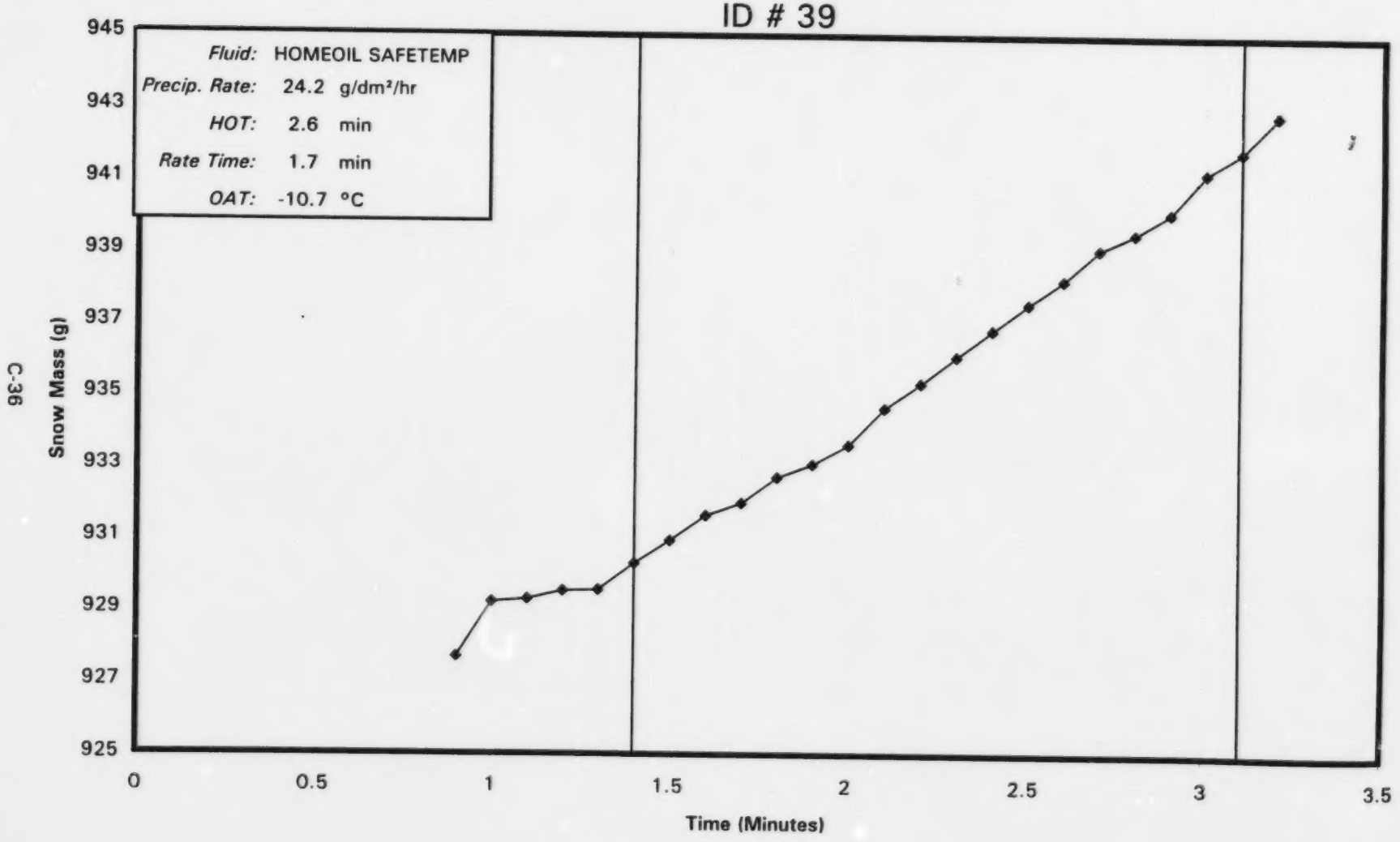
NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 39

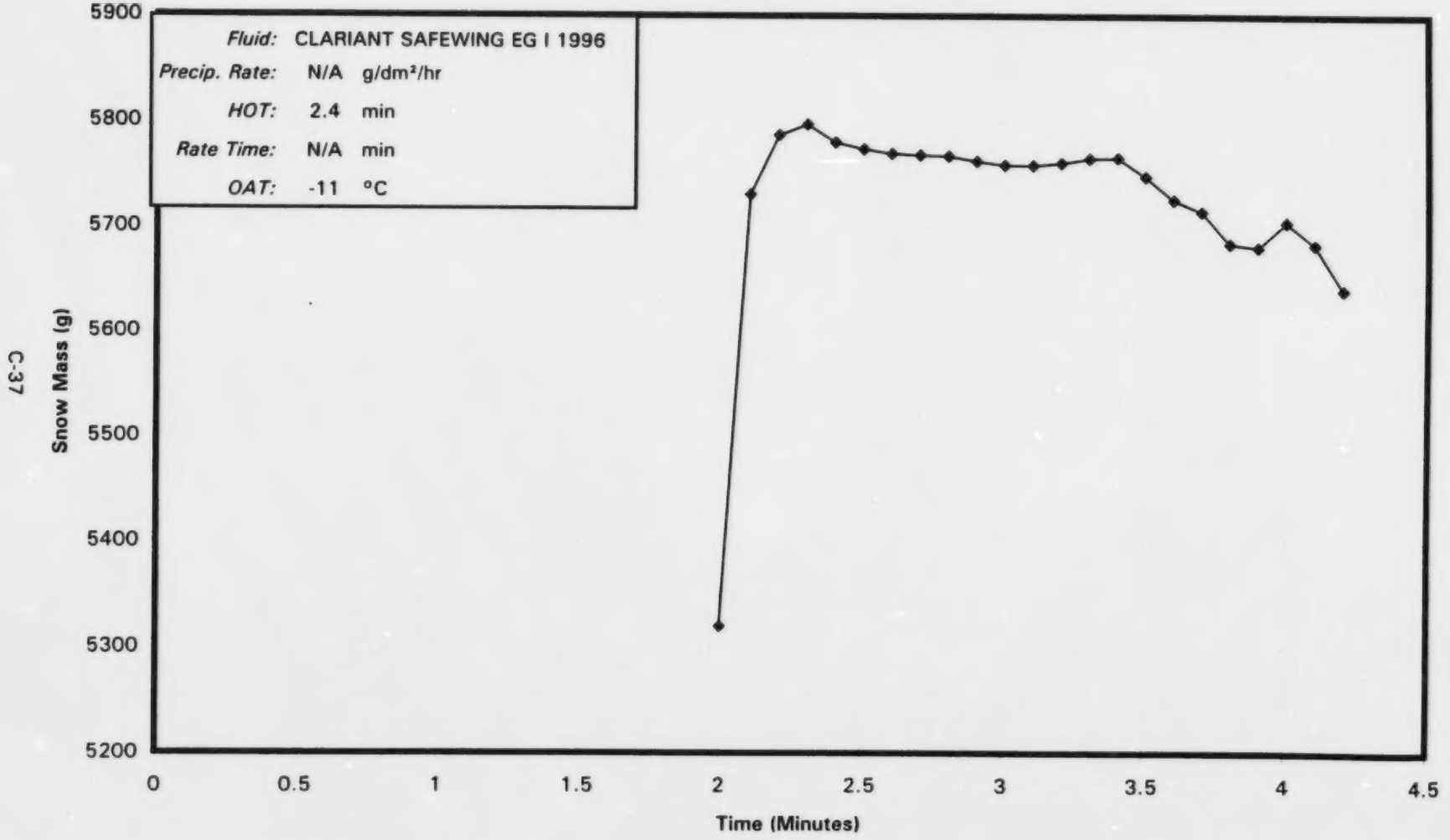


Id_39
9/24/99, 3:04 PM

NCAR SNOW MAKER

SNOW MASS ACCUMULATION

ID # 40



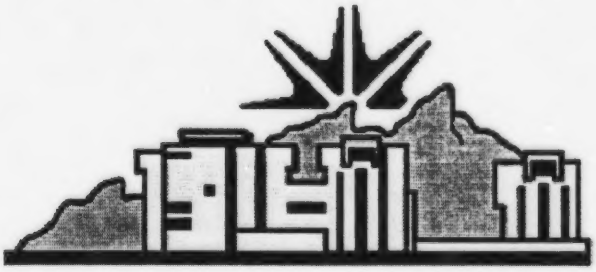
Id_40
9/24/99, 3:04 PM

APPENDIX D

NCAR SNOW MACHINE OPERATION MANUAL

NCAR Snow Machine

Operation Manual



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revision: 27 September 1999

Foreword

This manual should allow easy set up, and operation of the snow machine with a short learning curve. The instrument has been designed to allow easy access to power supplies, electronics, signal cables, A/D system, and essential subassemblies.

Be sure to read through this manual to learn the proper operation protocol for accurate and safe use of the snow machine. For further information, please contact Alan Hills at hills@ucar.edu.

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A. Theory of operation

The NCAR Snow Machine produces extremely fine ice shavings which mimic natural snow in; density, size distribution, fall velocity, and mass accumulation rates. In anti/de-icing studies, the snow has been demonstrated to be functionally equivalent to natural snow with a density of 0.1 g/ml.

The instrument operates by feeding a deionized-water ice core, 7 cm diameter x 1 m long, into a carbide-tipped spur bit at a controlled rate. The feed rate is determined by a series of high frequency pulses generated with a notebook PC and output to a stepper motor control circuit and to a stepper motor. The ice flakes are then redistributed in semi-random fashion by a series of fans, and then fall 2.2 m to a 30x50 cm^2 aluminum plate. The plate is part of a fluid containment unit that collects and weighs all the snow falling on the plate and also retains any de-icing fluid applied on the plate. The plate and fluid trap rest on an 0.1 g resolution/6100g capacity, analytical balance, so that total mass and snowfall rate may be measured in real time. The plate may be temperature controlled with a PID controller to 0.1 C. A high resolution (Analog Devices) temperature transmitter monitors a second temperature channel. Both temperature sensors use 1.5 mm o.d., 100 ohm platinum RTD sensing elements. The system may be used in anti/de-icing studies or other experiments.

B. Initial setup

1. Select an 8-foot high flat 30" x 45" area in a coldroom for placement of the machine. Leave an extra 24" of clearance to allow opening of the Lucite doors. 120 VAC power outlets should be available within 1 m.

2. Place upper stage onto lower stage and bolt together using ¼" x20 tpi bolts and nuts through the holes labeled "transport".

3. Place the electronic control box and notebook PC, outside the coldroom. Auxiliary monitor, keyboard and mouse are to reside inside the coldroom.

4. Place digital balance feet in the holes of the Lucite index board on bottom of snowmachine. Install containment tray on top of balance. Carefully do a visual check to be certain that the tray sits flat on the balance.

5. Check angle of snow plate to ensure lateral flatness and 10.0 degrees along the axis of the snow plate. Fine tune the angle using adjustable feet on balance.

6. Plug in all cabling. Ensure that cables going to the snow plate are loose (hanging freely). Tension in these cables will prohibit accurate mass readings. Ensure also that the cables do not block the freefall path of snow onto the plate.

C. Operation-experimental setup

1. Prepare ice core. Fill the aluminum ice core tubes with deionized water to a level 10 cm from the top edge. This allows for expansion of the mixture during cooling. Install the special insulation piece over the upper part of the tube. Install Let freeze for at least 12 hours.

2. Thaw PVC tube for 20-30 min. until the ice core will slip out of the tube via gravity. DO NOT HEAT THE TUBE using water or some other method, such heating will fracture the ice core.

3. Place the bare ice core back in the cold room for at least 10 minutes to refreeze the melted surface layer.

4. The electronic balance should *always* be left on. If the balance is currently off, turn on the balance and momentarily hold the tray away from the balance. Press "zero" on the balance and wait for 00.0g to appear, then place tray assembly back on balance. Be quite careful to position the tray on the top of the balance. It's easy to misplace the tray assembly.

5. Turn on the Electronic Control box.

6. Power-up PC and double-click on "APSsnow46.vi" (or current version). To allow both the notebook display and the external monitor (in the cold room) both to be active, press function key + F2 about 10 seconds after turning the PC on.

7. Start program execution by clicking once on the program start arrow (top left of control panel display, see Figure 1.). Temperature traces and other functions should now be operating.

8. Back the translator up sufficiently to load the ice core. This is done by flipping the ice translator toggle switch to the "on" position. The value stored in the "Snow rate" digital control may be altered to speed up translation speed. If the translator doesn't move either you forgot step 6 or one of the contact switches has been tripped. These switches reside at either end of the translator and prevent the translator from driving to far left or right.

To force translator movement, momentarily depress the red "limit switch" (~3 sec.) override on the front of the electronic control box.

> ****** CAUTION: Depressing the "limit switch" override while the computer is commanding the translator to move in the wrong direction, will result in major damage!!! *** The wrong direction would be "reverse" if the translator is at the left limit position and "snow" if the translator were at the right limit position. ******

9. Slide the ice core into the translator. Replace the #10-32 bolt in the translator (screw the bolt in finger tight). Slide the ice core to the left so that it rests against the bolt. Tighten the hose clamps snugly. (The #10-32 bolt pushes on the ice core during operation.)

10. Turn on "drill" and drive translator to the right (towards the drill bit) by clicking the "ice translator" to "on" and the "direction" toggle switch to "snow".

11. When snow shavings start to fall, stop translator. The system is now ready to perform a snow experiment. Note: The balance capacity is 6100g. If the indicated mass + what you are about to add (deicing fluid + snow loading) will exceed this, you should empty the tray by carefully lifting and tipping it to one side into a suitable reservoir. Be certain tray is properly seated when finished (see step 4.).

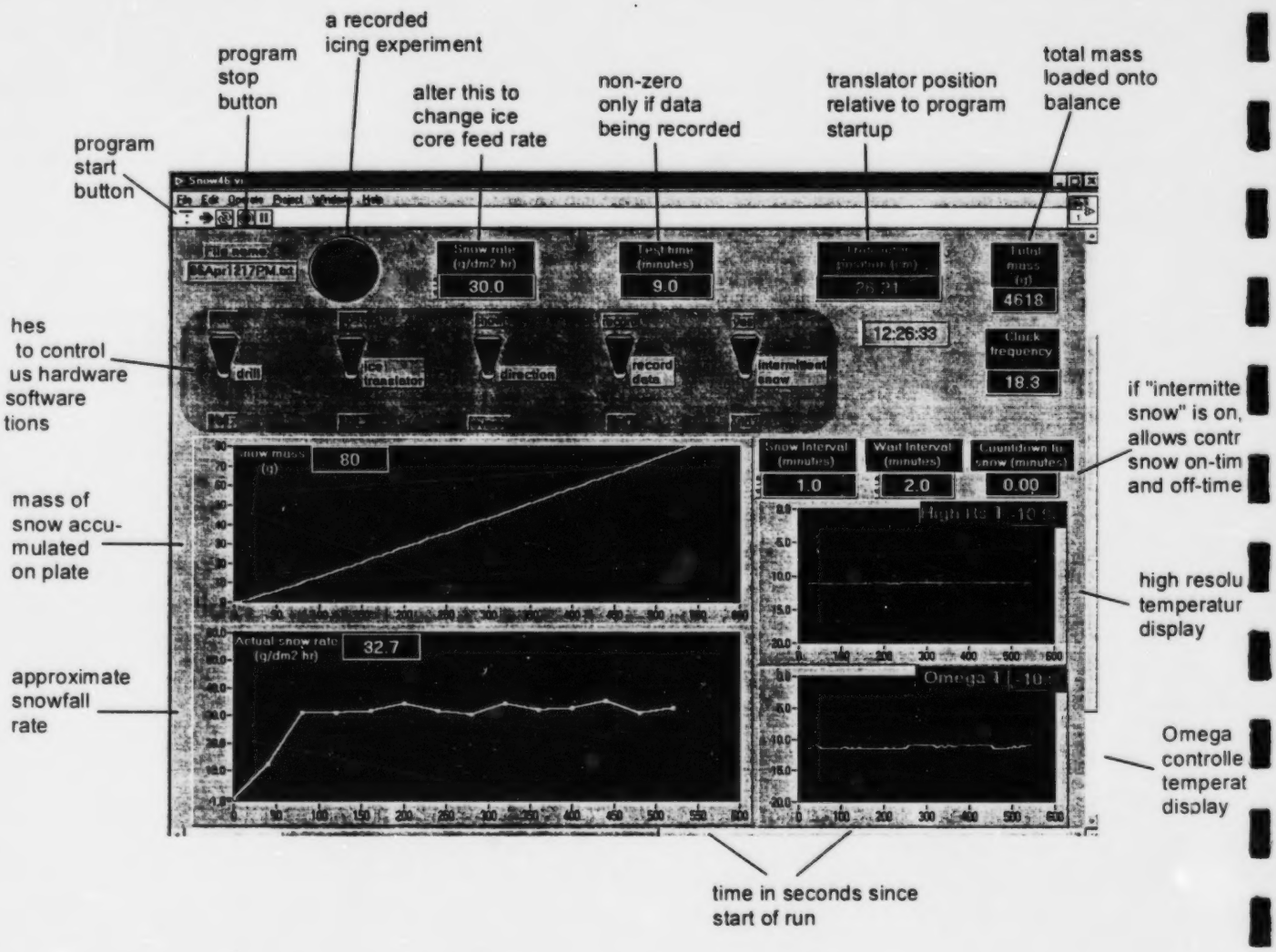

Figure 1. APSsnow46.vi code control panel

D. Conducting a snow experiment

1. Turn drill on, set translator direction to "snow", and enter desired snow rate.

2. Start translator. Advance ice core to point of contact with cutter.

3. Stop translator

4. Pour fluid on snow plate.

5. Hit "record data" and acknowledge the date/time stamp on output file, or rename the file. Note or redirect where the file will reside.

6. Start translator again.

7. Observe experiment and fluid failure.

8. When fluid has failed hit the large red "stop test" button. Enter comments and experimental details which will be written to the bottom of the data file.

9. If another experiment is to be performed, completely close out of "APSsnow46.vi" file using the "X" button on the top right of the window. This is necessary for proper reset of the code.

E. LabView code details

The LabView source code resides in drive D, in the NCAR folder.

Questions? Contact Alan Hills or LabView directly at 800 433-3488 or, 512 795-8248.

The address to their web site is: http://www.natinst

If the code is not working properly, close out of LabView and relaunch. If you still have problems, shut down and restart computer and cycle power on electronic control box.

If you accidentally move components on the PC "panel", hit control + z, for each step of undo. If it has really been screwed up, close the file *WITHOUT* saving changes.

F. Calibrations

Recalibration of measured/controlled snow machine parameters is occasionally needed. The calibration procedure is to carefully monitor the parameter against a fundamental measurement method, calculate and input a new calibration parameter into the APSsnow46.vi code.

Electronic balance

I recalibrated the balance parameters in April of 1999.

1. Warm up balance and data system for 1 hr. (its OK to leave them on continuously).
2. Monitoring the "total mass" readout (upper right display), add a calibrated mass to the balance.
3. If there is >2% discrepancy, calculate a correction factor.
4. At the APSsnow46.vi control panel, go to "windows" and "show diagram". Go to frame 9 of the code. There are four boxes in each quadrant of the screen. Go to frame 5 of the lower left box. Within box 5, go to frame 1 of the true case. Replace the "1.031" multiplier with a new factor *(Note: to replace text in a LabView diagram you have to enter text mode by clicking on windows and "show tools" and clicking once on the large "A")*. Go to "File" and "Save", to make the change permanent.

Omega temperature controller

1. Warm up controller and data system for 30 minutes.
2. Monitor "Omega T" readout on the PC. (*Note: The display on the actual Omega controller may have an offset error of ~1 °C.)* Compare the PC readout to a high accuracy (0.1 C or better) mercury thermometer or other suitable precision reference thermometer placed on top of the snow plate at 6" from top edge. If the difference between the two is large (> 0.6 °C), follow the recalibration procedure shown below.
3. Record reference temperature from the calibration standard of step 2. Also record "mean omega" voltage on the panel display (PC screen). This digital display is normally way off to the right of the normal display, but can be viewed by using the slider control at the bottom of the screen.
4. Use temperature controller to boost plate temperature say 40 °C higher than the coldroom value of previous step. Wait 30 min for thorough equilibration. Record values as in step 3.
5. Perform linear regression on the two points and compute appropriate values for "a" and "m" for an equation of the form: T = a + mV where T= temperature °C, a is intercept, m is slope and V is "mean omega" voltage.
6. At the APSsnow46.vi control panel, go to "windows"and "show diagram". Go to frame 9 of the code. There are four boxes in each quadrant of the screen. Go to frame 5 of the upper right box. Replace the slope and intercept values with those of the linear regression. Go to "File" and "Save", to make the change permanent. Calibration is complete.

High resolution temperature sensor

Calibration of the high resolution temperature sensor is identical to steps presented for the Omega calibration, *except* the parameters are held in frame 6 of the same code segment.

Snow rate calibration factor

The snow rate calibration factor is the parameter in APSsnow46.vi that ensures the desired snow rate will in fact be produced, during operation. To evaluate the accuracy of this factor, perform a snow experiment at a given rate, say 30 g $dm^{-2}hr^{-1}$, saving the data to a file. Then go to the ".txt" file created during the test and view the total mass of snow to collect on the plate and the test time in minutes. Calculate the actual rate via the equation:

$$\text{rate} = \text{snow mass} / (16.84\ dm^2)\ (\text{test time}/60).$$

Rate is the actual snow fall rate in g $dm^{-2}hr^{-1}$, 16.84 dm^2 is the area of the APS Aviation snow plate + that measured to the very edge of the collection tray (30x50cm + edges), test time is in minutes. If the measured rate differs from the mean command rate by more than 4 g $dm^{-2}hr^{-1}$. The code needs to be altered.

At the APSsnow46.vi control panel, go to "windows" and "show diagram". Go to frame 9 of the code. There are four boxes in each quadrant of the screen. Go to frame 4 of the upper left box. The new "constant" will be given by:

$$\text{constant}_{(new)} = \text{constant}_{(old)} \times (\text{command rate}/\text{actual rate})$$

G. Operational hints

- Don't leave ice cores in cold room for >12 hrs unless contained in PVC core. Sublimation will reshape core rendering it with incorrect shape.
- Leave balance on at all times. Memories and settings require power to hold values.
- Don't overfill PVC tubes.
- Check alignment guide and adjust if necessary. Ice core and guide friction can lead to unsteady snow rates.
- Plot range values may be reset during execution by clicking on the value and entering a new value. Then hit "enter" (top left) or moving cursor to another area and clicking once. The snow mass plot is set to autorange.
- To check snowfall pattern, place a dark plasticboard in the bottom of the snow machine. The board should cover most of the bottom area. Run the snow machine for 5-10 minutes and evaluate the pattern. Does the pattern produce uniform snow over the snow plate? If necessary redirect dispersion fans.

H. Parts ordering

Listed below are some of the components in the snow machine and their suppliers.

Component	Manufacturer & Part number	Distributor	Approximate cost
platinum RTD temperature sensor	Omega, RTD-2-1PT100K2515-36-T	Omega 800 826-6342	$80
Temperature controller	Omega, 76120-PV	Omega 800 826-6342	$270
Silicone heater for underside of snow plate	Omega, SRFG-101/10-P	Omega 800 826-6342	$62
Translator	Thomson Industries, 2DB08OUBAA x44.00"		$1700
Stepper motor electronic drive board and motor	CSK243-ATA, with 245 series, high torque motor	MSI, 303 792-5518	$300

I. Troubleshooting

Listed below are some symptoms and their possible causes and remedies. I've tried to think of several potential problems.

Symptom	Possible Cause	Remedy
Translator won't move, when commanded by computer.	Program not in run mode	Hit top left "run" arrow
	Limit switch activated	Reset limit switch as discussed in Section C step 8. Carefully observe the cautions presented!
	Ice core guide badly catching	Realign ice core guide.
	Stepper motor not getting 12 V	Turn on Electronic Control box.
Snow mass is way out of range	Code is "confused"	Restart code, or LabView, or PC
	Balance has not be tared properly	Reset balance zero as discussed in Section C step 4. Cycle balance power if needed. Balance power is cycled only by yanking the power jack out of the balance for >30s and then reinserting it.
Snow rate is very unsteady	ice core feed rate is varying	ice-core *guide* (the PVC collar near the drill bit) may be misaligned, realign it-carefully
	ice core might be slipping backward in translator as translator moves forward	thrust bolt behind ice core not installed or is damaged
Snow rate suddenly falls	ice core might be slipping backward in translator as translator moves forward	thrust bolt behind ice core not installed or is damaged

APPENDIX E

RECOMMENDED REFINEMENTS

Appendix E
RECOMMENDED REFINEMENTS

Please find here a list of observations that were made during our test sessions with the prototype snowmaking machine that you provided. Adding these changes to the unit that will replace our prototype would increase the effectiveness of the whole system.

1. A maintenance schedule should be developed and made to address key components. (e.g. Sharpening shaving blade)

2. The shaving blade should have top priority on the maintenance list. A dull blade exhibits particular symptoms: the snowflakes become thicker/denser and the ice core vibrates excessively (because the blade is no longer shaving but chopping), breaks often.

3. The coupling between the guide screw and motor should be verified to confirm that screws are tight and no slipping occurs. Dimples should be drilled into both the guide screw and the motor shaft to discourage slipping. Access to the coupling screws is very difficult.

4. The excessive variety in bolt and screw types makes maintenance tedious. The accessibility of screws should be considered in future designs.

5. The oversized guide ring should be fitted with three spring loaded guide screws (in a triangular layout) with rotating wheels on their tips. These would guide and reduce vibrations to the ice core. They should not cause excessive resistance to the translation of the core.

6. The pipe clamps used to brace the ice core at the base create point loads on the ice core and tend to induce cracking. The bracing-point loads should be distributed along a greater length of the ice core. This could be done by adding a metal support between the clamp and the ice core.

7. The gap between the weigh scale platform and the actual weigh scale (the gap that allows the platform to deflect when weight is added) has a tendency to accumulate fluid and snow. On occasion, the fluid freezes and does not allow the weigh scale platform to deflect naturally. Ultimately, this causes false readings. Precautions should be taken to shield this area from possible contamination.

8. The scale should be mobile, so that it can be moved into areas where good distribution is suspected.

9. Wire connections to the plate and reservoir make emptying the reservoir cumbersome.

10. Fans should have greater flexibility. They should have dials providing numerical bearings so that fan positions can be recorded and reproduced. The measure of degrees typically shown on a protractor could be a possible solution.

11. The ice core should be supported along its length. If unanticipated cracking occurs, the ice core would still be supported and the test could continue.

12. The butt screw, used to prevent the ice core from sliding away from the drill bit, creates a point load on the ice core. Replace it with something wider.

13. The test times should include seconds. This is particularly important when testing type 1 fluids.

14. Reconfiguring the software to include the following changes would make it better adapted to the testing protocol:

    - Open a file before the start of a test (e.g. 5 minutes before);
    - Push a specific button to start a test;
    - Push a specific button to stop the test;
    - Have the possibility of manually modifying the start and end times of the test, so that the rate is calculated on a specified interval;
    - Close the file;
    - The x-axis of the plotted graphs showing elapsed time should include seconds and should be in real time; and
    - Calculate the rate for the entire test's duration.

    These changes would allow us to monitor occurrences before and after the test. They would allow us also to correct any errors with the start and end times.

15. The snowmaker should have the capability of adjusting the rate of precipitation while the test is running. For example: if we want 25g/dm^2/hr and the rate happens to be 22 (while the test is running), the software should be able to accelerate the motor to achieve 25, on average, and avoid tossing out the test.

16. Ice-core sizes are in US units, which buying them in Canada impossible. I am not sure whether anything can be done to change this.

17. The balance gets overloaded after every test and must be emptied, because the weight (capacity) is exceeded.

18. If the weight during a test is decreasing, a signal or alarm should be displayed.

19. More fans might be needed to improve the distribution.

20. The text file should have the date and time (hh:mm:ss) added for each recorded line

21. A door should be added to the back of the machine for easier cleaning

22. Install a fan up near the translator guide to prevent snow from clumping.

23. A drainage valve should be added to the plate box to eliminate emptying and reduce time before the next test can begin

24. The weight scale should be tested to make sure it is sensitive enough to measure the snowflakes

25. The timing of the comment page (coming up right after a test is run) in the program is inconvenient; nothing can be done to the machine while comments are entered. The program should allow comments while the test is running.

26. If the cutting blade had four cutting edges, instead of two, would the flakes be smaller?

27. Replace the translator motor with one that has more torque power. The unit should be able to function at -35°C. The existing motor cannot turn the guide screw at lower end temperatures.

Recommended Refinements (continued)

If the software is modified to include a compensating clause, (system increases or decreases rate to obtain set-point rate), then placing a table or any shielding medium over the weigh scale during active snowmaking would create a false interpretation by the system. If snow is being created, but the weigh scale isn't recording a change in weight (due to shielding) then the system will acknowledge a zero rate and try to compensate by increasing the rate.

The solution to this is to include a "compensate -on" or "compensate off" function to the software.

The logistics would be as follows:

Calibration:

- Enter set point rate
- "Compensate-on"
- Allow system to stabilize and confirm uniformity of distribution
- Confirm that set-point rate has been obtained
- "Compensate- off"

The system should now maintain the last setting prior to hitting the "compensate -off" button. This includes step motor speed and drill speed. Note the system is no longer compensating, but is still producing snow.

Shield:

At this point a shield is added. The table you suggested may be restrictive and not ergonomically suited for the remaining steps in the procedure.

I suggest adding a 30° inclined surface approximately 1 foot below the cutting blade. The surface would have the same area as the cross section of the snow machine booth. In essence, when the surface is added, the snow being produced cannot fall past the surface and as a result doesn't affect the weigh scale. The bottom of the incline should lead to an opening in the sidewall of the snowmaking booth, allowing the accumulated snow to slide out the side of the machine.

Fluid pour:

After the shield is added, the plate is cleaned. At this point the ethanol/methanol is applied.
Then the fluid is poured.

Note: cleaning the plate in the chamber with ethanol/methanol is not an option! These products are extremely flammable.

The solution is to make detachable plates. Several plates would be used so that while one plate was being tested, another could be cleaned, and the others cooling.

The plates would have to be easily detached. All the wiring connected to the plate would also have to be quickly disconnected. This could be achieved using multiple pin plugs or open contact connections (like the ones between a portable phone and a it's charging base). Precautions need to be taken so that when the plate is replaced, it maintains its ten-degree slope.

The point supports for the plate should be strategically placed so as not to accumulate snow or ice during a test (this would affect the ten degree slope)

Test:
Five minutes after the fluid pour:
- The shield is removed.
- "Compensate-On"
- Wait for fluid failure

Note you may consider installing the "compensate-on/off" button on the booth itself.

Attached is a quick sketch of the design suggested.

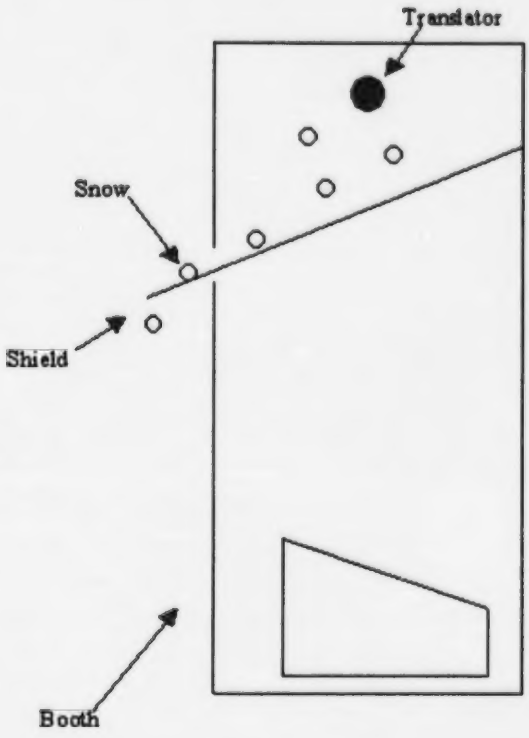

Figure 1: Sketch of Snowmaker Shield